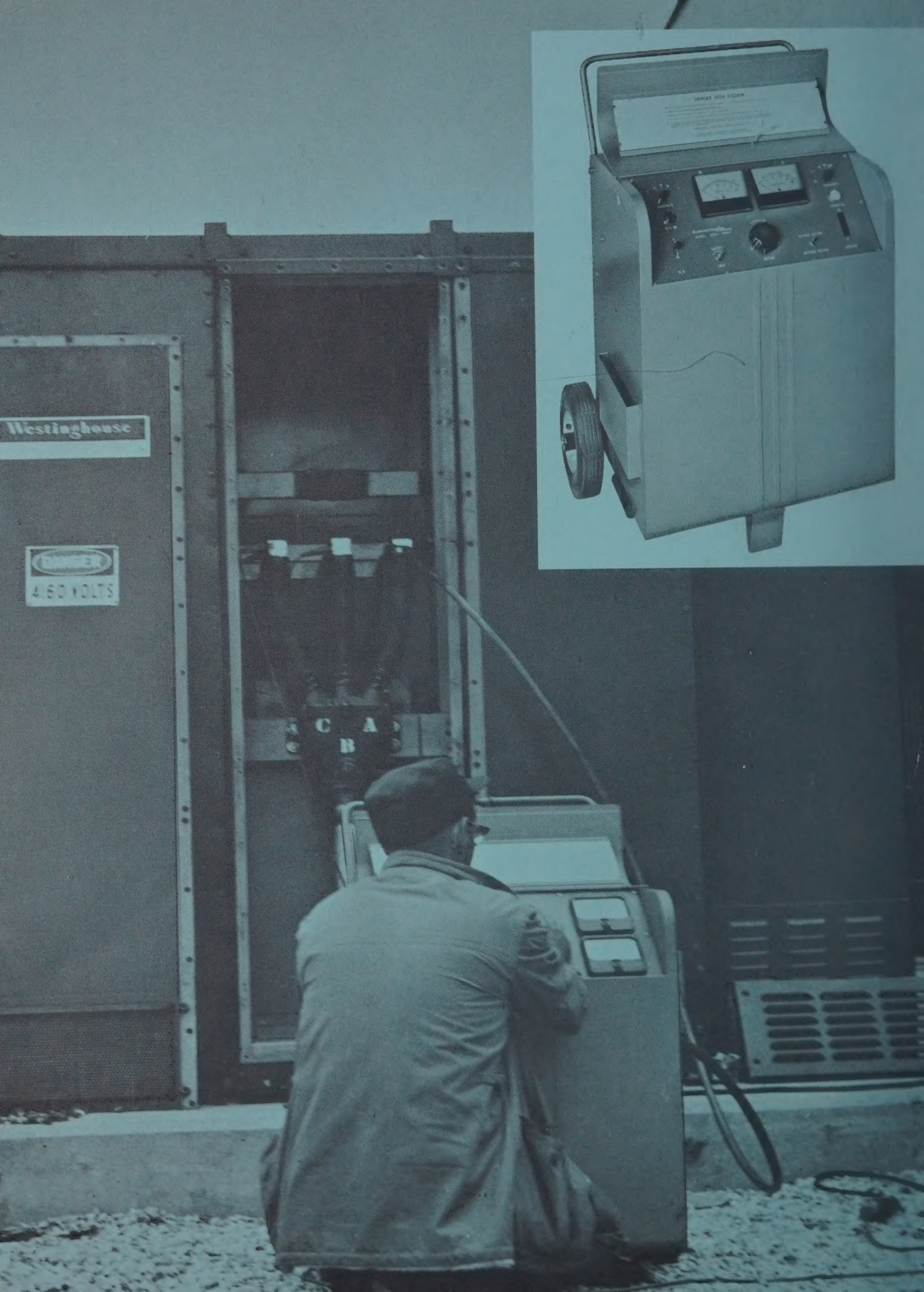
MANUAL P-16086

DC HYPOT® TESTING of CABLES, TRANSFORMERS and ROTATING MACHINERY

ASSOCIATED RESEARCH, INC.
6125 WEST HOWARD STREET, CHICAGO, ILLINOIS 60648


Westinghouse
DANGER
460 VOLTS

DC HYPOT® TESTING of CABLES, TRANSFORMERS and ROTATING MACHINERY

by
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DC HYPOT TESTING
of
Cables, Transformers and Rotating Machinery

• SECTION 1

Introduction

The DC HYPOT has been rapidly gaining favor as an important tool in determining the condition of insulation in cables, transformers, rotating machinery, etc. Properly conducted tests will indicate such faults as cracks, discontinuity, thin spots or voids in the insulation, excessive moisture or dirt, faulty splices, faulty potheads, etc. An experienced operator can not only frequently predict the expected breakdown voltage of the item under test, but often can make a good estimate of the future operating life.

The use of DC has several important advantages over AC. The test equipment itself may be much smaller, lighter in weight and lower in price. Properly used and interpreted, DC tests will give much more information than is obtainable with AC testing. There is far less chance of damage to equipment and less ambiguity in interpreting results. The high capacitance current frequently associated with AC testing is not present to mask the true leakage current, nor is it necessary to actually break down the material being tested to obtain information regarding its condition. Though DC testing may not simulate the operating conditions as closely as AC testing, the many other advantages of using DC make it well worthwhile.

• SECTION 2

Types of HYPOT Tests

HYPOT testing may be divided into the following broad categories:

A. Design Tests—These are the tests usually made in the laboratory to determine proper insulation levels prior to manufacturing.

B. Factory Tests—These are the tests made by the manufacturer to determine compliance with his design or production requirements.

C. Acceptance Tests—These are the tests made immediately after installation, but prior to putting the equipment or cables into service.

D. Proof Tests—These are the HV tests made soon after the equipment has been put into service and during the guarantee period.

E. Maintenance Tests—Maintenance tests are those performed during normal maintenance operations or after servicing or repair of equipment or cables.

F. Fault Locating—Fault locating tests are made to determine the location of a specific fault in a cable installation.

The maximum test voltage, the testing techniques, and the interpretation of the test results will vary somewhat depending upon the particular type of test. Unfortunately, in many cases the specifications do not spell out the test voltage, nor do they outline the test procedure to be followed. Therefore, it is necessary to apply a considerable amount of common sense and draw strongly upon past experience in making these tests. There are certain generally accepted procedures, but the specific requirements of the organization requiring the tests are the ones that should govern. It is obvious that an acceptance test must be much more severe than a maintenance test, while a test made on equipment that is already faulted would be conducted in a manner different from a test being conducted on a piece of equipment in active service.

As a rough rule of thumb, acceptance tests are made at about 80% of the original factory voltage. Proof tests are usually made at about 60% of the factory test voltage. The maximum voltage used in maintenance testing depends on the age, previous history and condition of the equipment, but an acceptable value would be approximately 50 to 60% of the factory test voltage.

In proof or acceptance testing, the prime consideration is the determination of whether the insulation will withstand the maximum voltage. In maintenance testing, it is more important that potential weaknesses be found out without actually causing breakdown. It is important that the test be carried at least beyond the normal operating voltage level to insure relatively safe continued operation.

Cable fault locating requires special techniques, and is covered in Sections 11 to 13.

• SECTION 3

DC HYPOT Test Techniques

DC HYPOT tests are performed primarily to determine the condition of the insulation. The magnitude of the ultimate breakdown voltage may or may not be of interest, but the relative condition of the insulation, in the neighborhood of and somewhat above operating voltage, is certainly required. While there are many ways of achieving these results, two of the most popular are the "Leakage Current vs. Voltage" test (Figure 1), and the "Current vs. Time" test (Figure 2). The "Current vs. Time" test is frequently made immediately after the "Current vs. Voltage" test and probably yields best results when performed in this manner.

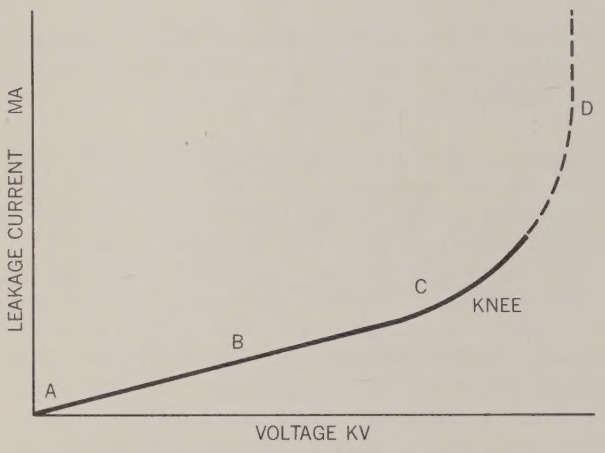


Figure 1. Leakage Current vs Voltage

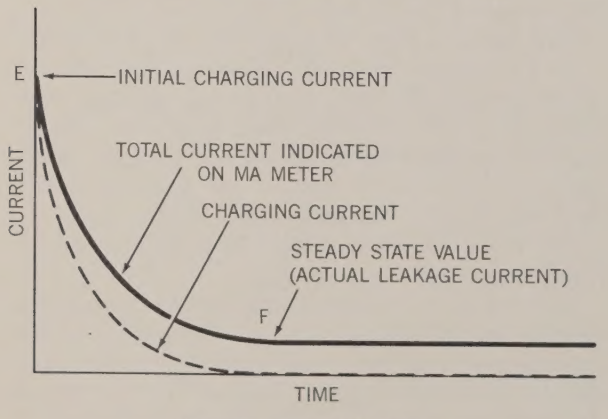


Figure 2. Current vs Time

Before performing a test, all accessory equipment, connected loads, potential transformers, etc. are disconnected from the cable or rotating machine being tested. The shield, frame and unused phases are grounded and the hot side of the HYPOT is connected to the conductor under test.

The voltage is slowly raised in discrete steps allowing sufficient time at each step for the leakage current to stabilize. It will be noted that as the voltage is raised, the leakage current will first be relatively high, then will decrease with time until a steady minimum value is reached (Figure 2, Points E and F).

The initial high value of current is known as the charging current, and is dependent primarily on the capacitance of the item under test. The lower steady state current consists of the actual leakage current and the dielectric absorption current (which is relatively minor as far as these tests are concerned). The value of the leakage current is noted at each step of voltage, and as the voltage is raised a curve is plotted of "Leakage Current versus Voltage." As long as this curve is relatively flat (equal increments of voltage giving equal increments of current, Figure 1, A to B), the item under test is considered to be in good condition. At some point the current will start rising at a more rapid rate (Figure 1, Point C). This will show up on the plot as a knee in the curve. It is very important that the voltage increments be small enough so that the starting point of this knee can be noted. If the test is carried on beyond the start of the knee, the current will increase at a much more rapid rate and breakdown will soon occur (Figure 1, Point D). Unless breakdown is actually desired, it is usual practice to halt a test as soon as the beginning of the knee is observed.

With a little experience, the operator can extrapolate the curve and estimate the point of breakdown voltage. It is this procedure that enables the operator to anticipate the breakdown point without actually damaging the insulation, for if the test is stopped at the start of the knee, no harm is done.

While the important thing to watch for is the rate of change of current as the voltage is raised, much information may be obtained from the value of the current. A comparison of the leakage current from phase to phase, or a comparison of leakage current with values measured in other equipment under similar conditions, or a comparison with the leakage current values obtained on tests made of the same equipment on prior occasions, will give an indication of the condition of the insulation. In general, higher leakage current is an indication of poorer insulation. However, this is a matter difficult to evaluate from a single test. But as long as the curve of "Leakage Current versus Voltage" is of the general shape shown in Figure 1, and as long as the knee occurs at a sufficiently high voltage (above the maximum test voltage required), the equipment being tested may be considered satisfactory.

On long cable runs or with rotating machinery having high capacitance between windings, or from winding to frame, the time for stabilization of the leakage current (decrease from E to F in Figure 2) may run as high as several minutes or several hours or more. To minimize the testing time under these conditions, it is common practice to time the decay of current and to take a reading at each voltage step after the same fixed interval. For example, voltage could be brought up to the first step, allowed to remain at that point for four minutes and then the current reading taken. The voltage is next raised to the second step, the same four minute wait is allowed and current reading again taken. This is continued throughout the test. While this method will not give the true leakage current at any point, it will still give the properly shaped curve and will still permit much the same evaluation.

When the final test voltage is reached, the HYPOT is left on and the "Current versus Time" curve (Figures 2 and 3) is plotted by recording the current at fixed intervals as it decays from the initial high charging value to the steady state leakage value. This curve for good cable should indicate a continuous decrease

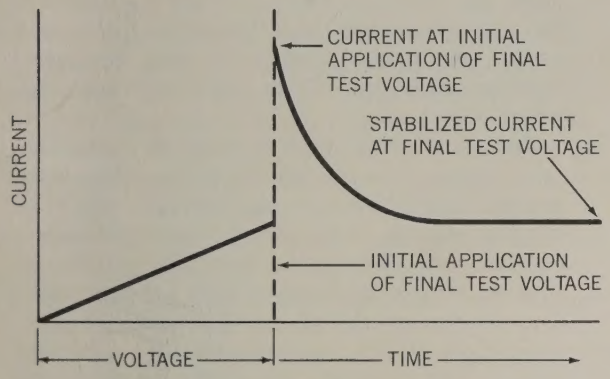


Figure 3. Current vs Voltage and Current vs Time at Maximum Voltage

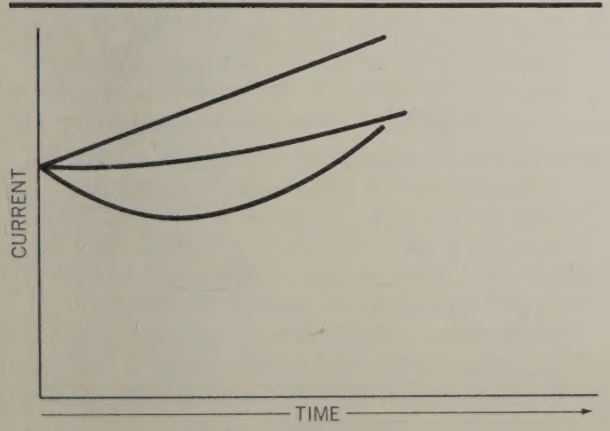


Figure 4. Faulty Insulation

in leakage current with time or a stabilization of the current without any increase during the test.

Any increase of current during this test would be indicative of a bad cable or machine. The test should, of course, be stopped immediately if such an indication occurs (see Figure 4). After the current has stabilized and the last reading taken, shut off the high voltage. The kilovoltmeter on the HYPOT will indicate the actual voltage present in the equipment under test as the HYPOT's internal circuitry permits the charge to gradually leak off. After the voltage reaches zero (0), put an external ground on the cable or machine and disconnect it from the HYPOT. It is important to wear rubber gloves at this point, since the effect of absorption currents may cause a build-up of voltage in the item under test until after it has been grounded for some time.

• SECTION 4

Selective Guard Circuits

When making the "Current versus Voltage" test, a rapid climb in current may occur not due to defects in the equipment itself, but because of surface leakage or corona at the connections, cable ends, blades of connected switches, etc. All ARI DC HYPOTS incorporate internal circuitry (ARI selective guard circuit) to bypass this stray current so that it does not interfere with the leakage measurements. By proper use of the guard circuit and corona ring, when necessary (described in Section 7), good leakage current readings even below one microampere can be made. This technique consists of providing a separate path for these stray currents, bypassing them around the metering circuit, and only feeding the leakage current to be measured through the metering circuit. In order to accomplish this, ARI DC HYPOTS have two return paths: (1) the METERED RETURN binding post which provides a return path through the microammeter circuit and (2) the BYPASS RETURN binding post which provides a return path bypassing the meter. Currents entering the first binding post will be measured, while currents entering the second binding post will not be measured. A panel switch is provided to connect the cabinet ground internally to either of these two binding posts (which enables ground currents to be measured or bypassed, depending on the test being performed).

• SECTION 5

Connections

Before performing any test, it is important that the test operator carefully plan the test procedure and

connections so that the required measurements may be taken without misinterpretation or error.

All possible safety precautions must be taken. Equipment to be tested must be de-energized and grounded to eliminate any charge. Switches should be open, jumpers running from potheads to feeders must be disconnected, potential transformers and lightning arresters disconnected. If their insulation level is sufficiently high, current transformers might be left in the circuit.

1. Make sure the main ON-OFF switch is turned to the OFF position; that the high voltage ON switch is in the OFF position, and that the voltage control is turned fully counter-clockwise to the zero voltage position.

2. Connect a grounding cable from the safety ground stud of the HYPOT to a good electrical ground, and make sure the connection is secure at both ends. It is essential that this connection be made. At no time should the HYPOT be operated without it.

3. Connect the return line from the item under test to the METERED RETURN or BYPASS RETURN binding post of the HYPOT, as described in further detail in Section 6, and operate the grounding switch on the HYPOT panel to the appropriate position. The return lines connected to either the BYPASS RETURN or METERED RETURN binding post should be insulated for about 100 volts, so ordinary building grade wire may be used.

4. Plug the shielded high voltage cable furnished with the HYPOT into the receptacle at the top of the unit. If the HYPOT has an oil filled output receptacle, make sure that the oil level is at the mark indicated on the oil stick. If the oil level is low, add the proper amount of high grade transformer or other insulating oil. After the high voltage cable is plugged into the receptacle, tighten the clamping nut to hold it securely in place.

5. Connect the shield grounding strap from the cable to the shield ground stud on the HYPOT adjacent to the high voltage receptacle.

6. Connect the other end of the output cable to the item under test. This connection should be made mechanically secure avoiding any sharp edges. It is usually advisable to tape the connection using a high grade electrical tape to minimize corona at this point. If the voltages to be used are high, or if for any other reason corona is anticipated, its effect may be minimized by making use of a corona ring or corona shield, as described in the next section.

7. If a bench type HYPOT or any other unit having an output bushing rather than a high voltage receptacle is used, the same procedure is followed except that the output cable is fastened to the bushing and should be supported along its length, preferably using nylon cord so that it stays well away from any grounded or other conducting surface. The high voltage connection between the HYPOT and the item under test should be as short and direct as possible.

8. When shielded cable is used, it is important that the shield be trimmed back from each end for a distance of about an inch or more for every 10,000 volts. The shield at the HYPOT end should be fastened to the ground stud on the HYPOT. The shield at the test end should be taped and no connection made to it.

9. If the item under test is beyond the reach of the HYPOT cable supplied, an extension running between the end of the HYPOT cable and the item under test must be used. If this extension is made of shielded cable, it is necessary to splice not only the central conductor to the end of the HYPOT cable, but a jumper should connect the shields of the two cables together at the splice, taking care to run the jumper well away from the splice itself to avoid leakage or even breakdown between the two.

   The splice should be well taped. If no shielded high voltage cable is available, the single wire extension used should be supported well away from all other objects, as described. When operating at voltages within the corona levels, it is preferable that the HYPOT be brought close enough to the item under test so that an extension cable is not needed. It should be noted that the extension cable is a frequent cause of erratic readings, especially if the quality is not good enough at the high voltage used.

10. Plug the line cord into the 115 volt, 60 cycle, single phase outlet and clip the ground wire coming from the line cord to the conduit receptacle mounting screw or other ground source.

11. When line regulation is poor (because of location, heavy or intermittently loaded equipment in the vicinity, or due to the use of portable generating equipment) it may be necessary to connect a voltage regulator between the HYPOT and the 115 V. supply. The use of a regulator is particularly desirable when using a HYPOT with sensitive vacuum tube current meter with ranges of less than 10 microamperes full scale, or when highly capacitive loads are being tested.

    Since the DC output voltage of the HYPOT is de-

pendent on the AC line input voltage, an unstable line voltage will cause fluctuation of the HYPOT output voltage with corresponding fluctuation of the current meter. This will be especially noticeable when measuring low current of the order of a few microamperes or when testing loads having considerable capacitance. When the load is highly capacitive it charges up to the test potential and tends to maintain that potential because of the high leakage resistance. A sudden drop in line voltage causes the HYPOT output voltage to also drop, so that the load capacitance is then charged to a higher value than the HYPOT output. Since the load is at a higher voltage than the HYPOT the direction of current flow will be reversed and the current meter will be driven down scale. A sudden increase in line voltage would cause the opposite effect, the HYPOT voltage suddenly rising above the voltage to which the load has been charged, causing a rapid increase in the current meter reading. As a result the current meter will fluctuate so that it might be difficult to obtain a meaningful leakage current reading.

The use of a line voltage regulator under such conditions will greatly increase the usefulness and ease of operation of the equipment. In general the power rating of the regulator should be based on the maximum power output capability of the HYPOT multiplied by the factor of about 1.3. For example the Model 5280 HYPOT rated at 75 KV @ 2.5 milliamps can deliver an output power of 75 $\times$ 2.5 or 187.5 watts. 187.5 $\times$ 1.3 equals 243.75 watts so a 250 watt regulator should be used. The harmonic free type of regulator is preferable to the standard type unit though either may be used with satisfactory results. If considerable testing at very light loads is done, it might also be desirable to have a smaller regulator to use under those conditions, since a small regulator operating at half to three-quarters of its capacity will give better results than a lightly loaded large regulator.

A method of connecting a voltage regulator is shown in Figure 13.

12. Turn the microampere range switch to the highest range. On multiple voltage range units, turn the kilovolt range switch to the range that will allow testing to maximum voltage required. It should be noted in this connection that the microampere range may be changed while test is under way, but the kilovolt range may not. Safety interlocks within the unit will automatically shut off high voltage as the voltage range switch is turned while the test is in progress.

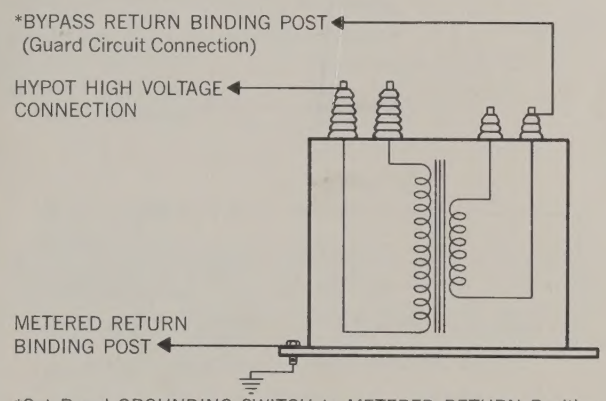
13. The main power switch or circuit breaker may now be turned ON and the test begun.

The sketches given in Figures 5 through 13 illustrate typical connection diagrams. The experienced operator will soon develop the knack and technique of making connections most suitable to the test he is performing. The sketches are merely offered as a guide.

NOTE: In the various connection diagrams given here, the guard circuit may be omitted by tying the connections shown going to the BYPASS RETURN binding post to the METERED RETURN binding post instead. This is the difference shown by the connections in Figure 9 and Figure 10.

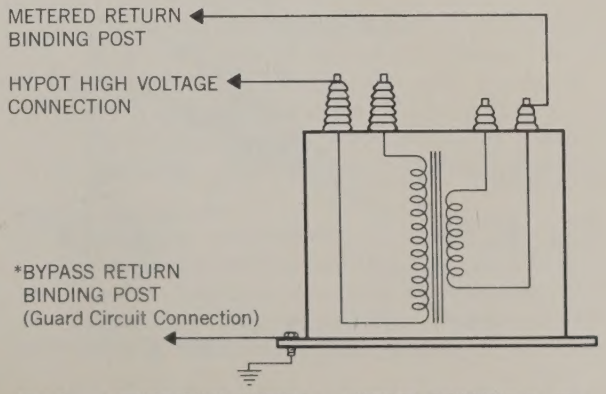
If this return path is grounded, set the panel GROUNDING SWITCH to the METERED RETURN position. Total load current (leakage, corona, etc.) will be read on the meter.

If the return path is not grounded, set the panel GROUNDING SWITCH to the BYPASS RETURN position and the effect of corona currents on the meter reading will be minimized.



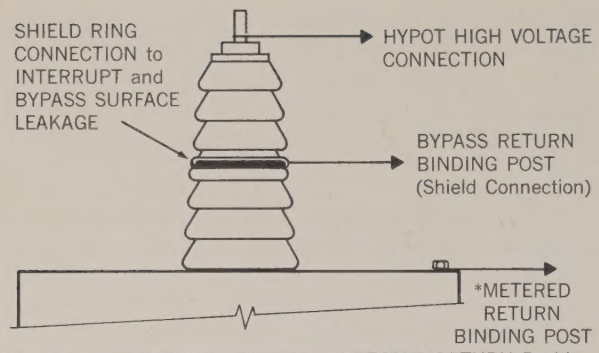
*Set Panel GROUNDING SWITCH to METERED RETURN Position

Figure 5. Testing Transformer Winding Insulation; High Voltage Winding to Grounded Core or Case



*Set Panel GROUNDING SWITCH to "BYPASS RETURN" Position.

Figure 6. Testing Transformer Winding Insulation; High Voltage Winding to Low Voltage Winding



*Set Panel GROUNDING SWITCH to METERED RETURN Position

Figure 7. Measuring Bushing Leakage (and Eliminating Effect of Surface Leakage)

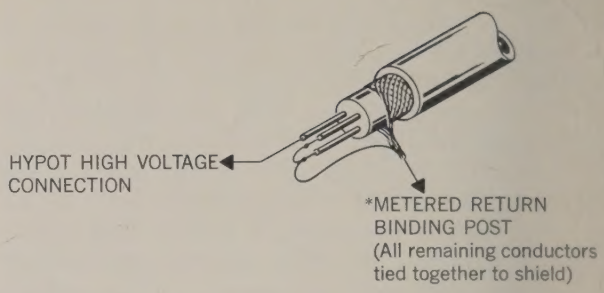
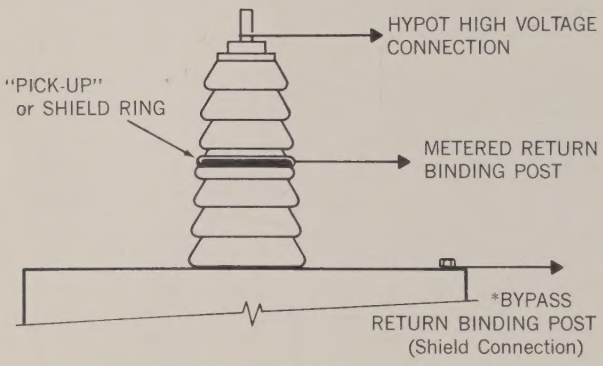
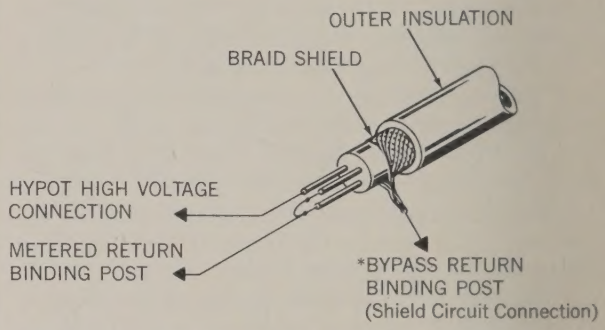


Figure 10. Testing Cable Insulation Between One Conductor and all Others and Shield



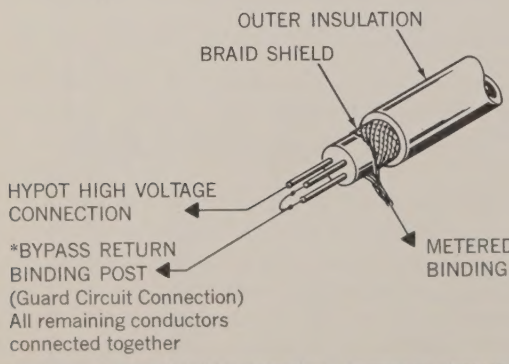
*Set Panel GROUNDING SWITCH to BYPASS RETURN Position

Figure 8. Measuring Surface Leakage of a Bushing



*Set Panel GROUNDING SWITCH to BYPASS RETURN Position

Figure 11. Testing Cable Insulation Between Conductors



*Set Panel GROUNDING SWITCH to METERED RETURN Position

Figure 9. Testing Cable Insulation Between One Conductor and Shield

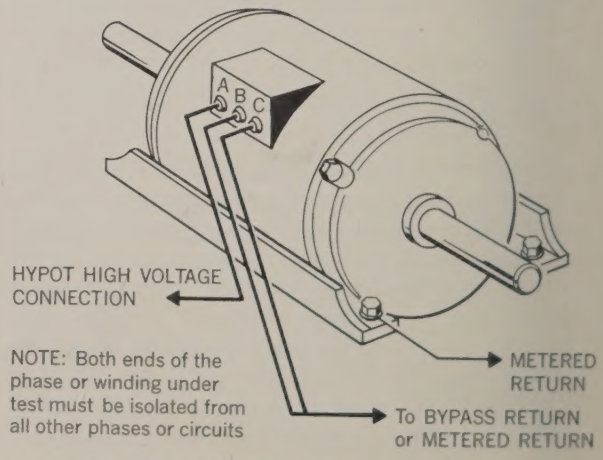


Figure 12. Testing Motor Winding Insulation— One Winding to Grounded Core or Case

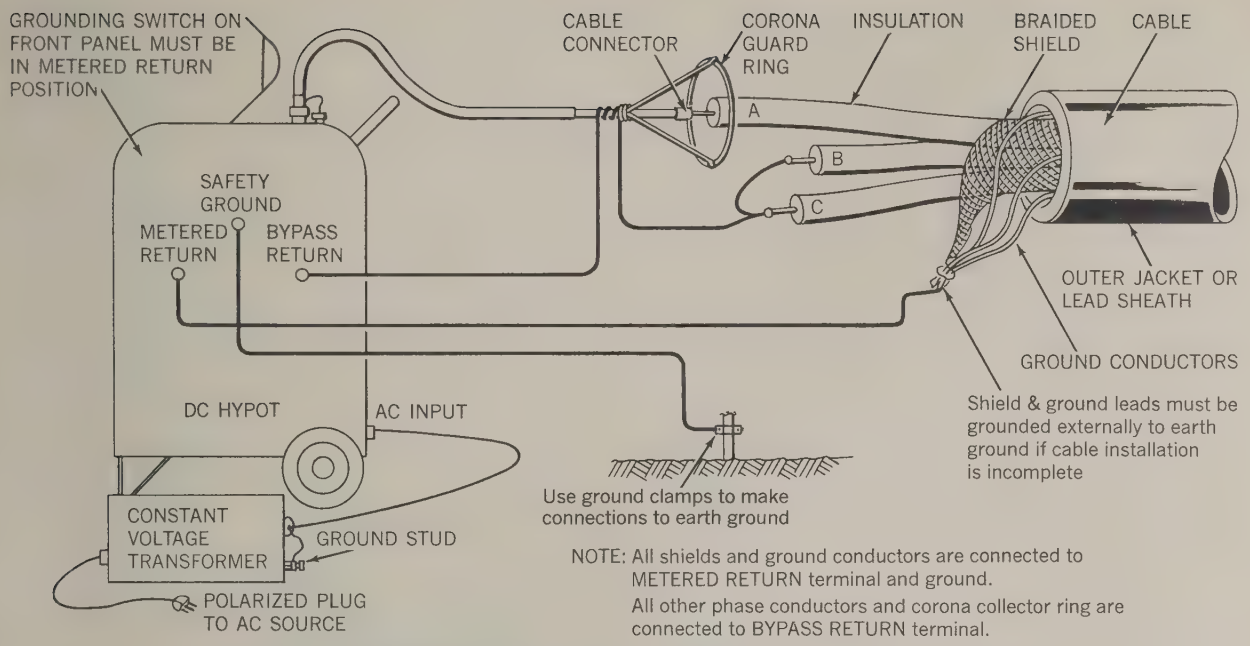

GROUNDING SWITCH ON FRONT PANEL MUST BE IN METERED RETURN POSITION
CABLE CONNECTOR
CORONA GUARD RING
INSULATION
BRAIDED SHIELD
CABLE
A
B
C
SAFETY GROUND
METERED RETURN
BYPASS RETURN
OUTER JACKET OR LEAD SHEATH
GROUND CONDUCTORS
Shield & ground leads must be grounded externally to earth ground if cable installation is incomplete
DC HYPOT
AC INPUT
CONSTANT VOLTAGE TRANSFORMER
GROUND STUD
POLARIZED PLUG TO AC SOURCE
Use ground clamps to make connections to earth ground
NOTE: All shields and ground conductors are connected to METERED RETURN terminal and ground.
All other phase conductors and corona collector ring are connected to BYPASS RETURN terminal.

Figure 13. Typical HYPOT Connections for Testing Multiple Conductor Shielded Cable
Drawing Shows Test of Phase "A" to Shield

• SECTION 6

Selective Guard Circuit Connections

In the connection diagrams (Figures 5 through 13), frequent reference is made to the BYPASS RETURN or METERED RETURN binding post. The simplified sketch of the HYPOT output circuit shown in Figure 14 will aid in understanding the use of these terminals.

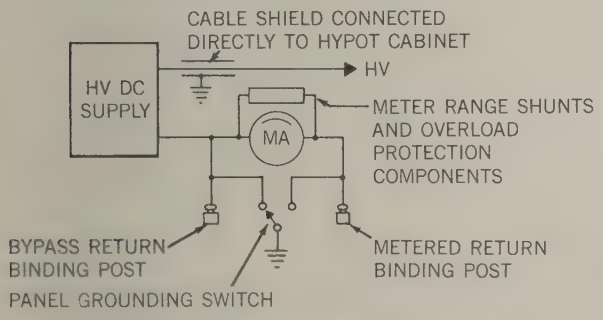


Figure 14. Simplified HYPOT Output Circuit

Examination of the sketch will show that any current to be measured should be returned to the HYPOT through the METERED RETURN binding post and any current which is not to be measured, but is to be bypassed around the meter should be returned to the BYPASS RETURN binding post.

As corona currents flow from the high voltage connection to ground, they may be bypassed around the microammeter by grounding the BYPASS RETURN binding post with the grounding switch on the control panel. This gives a direct return path back to the high voltage supply for corona currents and bypasses them around the meter.

For purposes of illustration, assume a three-conductor shielded cable is to be tested for leakage current between one of the conductors and the outer shield. To make the proper HYPOT connection, the test should be analyzed as follows (see Figure 13):

1. The current which is to be measured must return to the low side of the HYPOT through the METERED RETURN binding post; therefore, the HV connection should be made to the one conductor in question and the shield should be connected to METERED RETURN binding post.

2. Since the measurement of current flow between the HV connection and the other two conductors in the cable is not desirable, these two conductors should be connected together and returned to the BYPASS RETURN binding post.

3. In order to minimize the measurement of the corona current from the HV connection to ground,

the BYPASS RETURN binding post should be grounded by setting the grounding switch on the control panel to BYPASS position. This will provide a return path for the corona current around the meter and the corona current will not affect the meter readings.

A further analysis of the same cable will show the following:

1. To measure the leakage current between the one conductor and the other two conductors (which are tied together), the return path for the two conductors should be through the METERED RETURN post and the shield should then be connected to BYPASS RETURN post. Again, to minimize the measurement of the corona current, the grounding switch should be in BYPASS RETURN position.

2. The corona current alone may be measured by connecting the shield and the two conductors together and connecting them to the BYPASS RETURN binding post. If the grounding switch is then placed in METERED RETURN position, the return path for the corona current will be through the microammeter and the corona current will be the only current being measured.

Generally speaking, the GROUNDING SWITCH on the control panel will either include or exclude the corona current in the meter reading, depending upon its position.

It was assumed in the above example there was no restriction placed on the cable with respect to grounding. This was done to illustrate the general case. In many cases, however, the shield is permanently grounded, and therefore certain modifications in the test setup must be made in order to achieve corona-free stability and accuracy in the leakage current readings.

If it is desired to measure the leakage current from one conductor to shield, the shield should be connected to the METERED RETURN binding post as before. But since the shield is now permanently grounded, the METERED RETURN binding post should also be grounded by placing the panel grounding switch in METERED RETURN position. If the panel grounding switch were placed in the BYPASS RETURN position, then the METERED RETURN post and the BYPASS RETURN post would both be grounded, shorting out the microammeter.

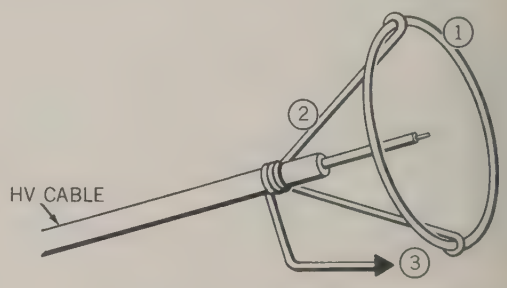
Therefore the GROUNDING SWITCH must be put in the METERED RETURN postion when one side of the test item is permanently grounded.

As outlined above, all unwanted currents which flow between the HV point and any ungrounded elements in the cable may be returned through the bypass line and therefore be excluded from the leakage current reading. This does not, however, include corona current since corona current always flows between HV and ground. Since we cannot shunt the corona current around the microammeter by grounding the BYPASS RETURN line as we did before, we must use some auxiliary method of intercepting the corona current before it reaches ground. This can easily be accomplished by the use of a "corona" or "guard" ring. A "corona" or "guard" ring is nothing more than a metal loop which encompasses the HV connection and intercepts the corona current. The ring is connected to the HYPOT through BYPASS RETURN binding post and therefore keeps the corona current out of the meter reading.

• SECTION 7

Corona Guard Ring and Corona Shield

A simple but very effective guard ring may be constructed as illustrated in Figure 15.



1. No. 8 or No. 10 copper wire bent to form a ring about 16″ in diameter. The two ends of the wire overlap so that the diameter of the ring is adjustable.
2. Use same wire to clamp ring together and to form two struts to hold ring in place on outer insulation of cable. The corona ring must be insulated from the cable shield.
3. Wire from ring: connect to BYPASS RETURN binding post.

Figure 15. Guard Ring

When using the corona ring, the diameter should be made as small as possible, without causing an arc to jump between the HV connection and the ring. This will insure as much corona current as possible being intercepted. A wire should be connected to the ring as shown in the illustration, and the other end should be connected to the BYPASS RETURN binding post. This will bypass the intercepted corona current

around the microammeter and will allow essentially the same stability and accuracy which was obtainable in the first example.

Corona may also be minimized by electrically shielding or smoothing the connection. This may be done by smoothly wrapping it with metal foil or conductive tape or enclosing it in a round can or cover so that all jagged edges, wire points, or rough surfaces are within the metal enclosure. This corona shield must be electrically connected to the high voltage and completely insulated from ground so that both the shield and high voltage connection are at the same potential. A suitable corona shield is illustrated in Figure 16.

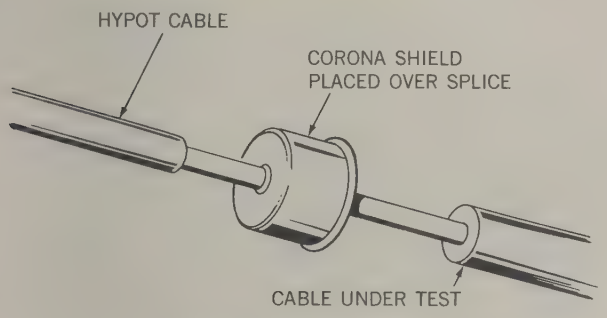


Figure 16. Corona Shield

• SECTION 8

Detailed Operating Procedure

The step by step instructions given below are meant to illustrate a typical operating procedure. In an actual test, account must be taken of special conditions peculiar to the installation, ranges and operating controls of the HYPOT available, and requirements of the operator.

1. Assemble the necessary equipment and supplies at the test site. In addition to the HYPOT, connecting cable, and so forth, a clip board or other writing surface, pencils, colored pencils, scratch paper, sheets of 8½″ by 11″ graph paper (which is very convenient for actually plotting the test results while the test is under way) and even a slide rule are desirable.

2. Determine the type of test to be made; i.e., is the voltage going to be raised to breakdown, or is the voltage going to be raised to the specific test value only? If the item on the test is found to be defective, should the test stop before breakdown until the repairs can be made at a later date, or should the test be continued to the preselected value regardless of breakdown so that repairs could be made immediately?

3. Determine the maximum test voltage to use. Since the value chosen depends not only on the type of test being made, but also on the material to be tested, it is necessary that all factors involved be considered. As a rough rule of thumb, proof testing is usually conducted at 60% of the factory test voltage. Acceptance testing would call for a maximum value of about 80% of the factory test voltage. For maintenance testing or on older work, the minimum test voltage chosen should be at least 1.7 times the operating voltage up to a maximum value of between 50 or 60% of the factory test voltage.

   In many cases, the value of maximum test voltage to be used may be obtained from the IPCEA or AEIC specifications, or from manuals available from Rome Wire and Cable Company, Simplex Wire and Cable Company or others (see Bibliography, Section 20).

4. Choose suitable increments so that the voltage may be raised to the final test value in about eight to ten steps (more or less to suit the individual conditions).

5. Once the maximum test voltage and the increments have been chosen, the graph paper may be prepared so that the test results can be plotted as the readings are taken. In this way, the condition of the cable is under constant surveillance and if testing short of breakdown is decided upon, the operator has necessary control to stop the test at the start of the knee of the current versus voltage curve. To prepare the graph paper, mark the current scale on the 8½″ side and the voltage scale along the horizontal 11″ side. Suitable voltage increments should have been chosen to give a convenient plot. The current scale should include values well above the expected maximum leakage current. If the magnitude of leakage current is not known, it may be advisable to either make a low voltage test run, or to hold off plotting the first few points until the magnitude is seen.

6. Connect the HYPOT to the equipment under test, as described in Section 5.

7. Make sure the adjustable voltage control is turned to the OFF position (fully counter-clockwise); the high voltage switch is in the center or OFF position, and the power switch is in the OFF position. Connect the input line cord to the 115 volt, 60 cycle receptacle and connect the alligator clip at the end of the line cord to ground (usually the conduit or the screw holding the receptacle in place is satisfactory).

8. Turn the kilovoltmeter range switch and microammeter range switch to appropriate positions.

9. Turn the main ON-OFF switch or circuit breaker to the ON position.

10. Operate the high voltage ON switch. Note that the lever type high voltage switch has a spring return from the DOWN position but will remain in the UP position. If it is desired to keep the high voltage under strict manual control, use the DOWN position of the high voltage switch. As soon as it is released to the OFF position, high voltage will be turned off and it will become necessary to return the powerstat control to zero before the high voltage can be re-applied. If the high voltage switch is placed in the UP position, the switch may be released and will remain in the UP position and high voltage will be available until the switch is manually returned to the center OFF position. On units with a key interlock, it is necessary to turn the key to the right to enable the UP position of the high voltage lever switch to be operated.

11. Slowly rotate the variable voltage control from the extreme counter-clockwise position (zero volts) to raise the voltage to the first increment as previously determined. The voltage should be raised at a slow enough rate to avoid having the microammeter pointer go off scale. The slower the voltage is raised, the lower will be the maximum charging current and microammeter reading. If the charging current is allowed to exceed the maximum current rating of the HYPOT, the circuit breaker will trip. The circuit breaker will also trip if the unit under test fails. Since most ARI HYPOTS are equipped with zero return interlocks for operator safety, it is necessary to return the voltage control to the zero position before high voltage can be re-applied once it is shut off, whether due to circuit breaker tripping, kilovolt range selector switch rotating or operation of the high voltage ON lever switch to the OFF position.

12. When the first increment of voltage is reached, watch the microammeter indicate gradually decreasing current as the cable or machine under test becomes charged. As the current drops to lower portions of the scale, switch the microammeter progressively to lower ranges until the current stabilizes. Note the length of time it takes for the current to stabilize. More accurate results can be obtained if the same stabilization period is allowed at each voltage step. After the current is stabilized, whether it takes 10 seconds, a minute, or 10 minutes, record the value of voltage and current.

13. If the microampere scale for plotting the current versus voltage curve has been predetermined, the current reading at the first voltage step can now be plotted. If the scale has not yet been determined, it might be wise to just record this value and after a few more increments a scale could be determined and the plotting take place.

14. After the current is stabilized and a point plotted, turn the microammeter range switch back to the higher range and gradually raise the voltage to the next increment. Allow the current to stabilize the same length of time as previously determined. Take a second reading and continue the test, gradually raising the voltage step by step and plotting the current versus voltage at each step.

15. Closely watch the rate of change of current at each voltage increment. The curve should indicate a linear (even) rate of change up to the final test voltage. If this is the case, the material being tested is all right (Figure 1, Points A to B). Upon any indication of a rapid rise in current (Figure 1, Point C), stop the test immediately, unless, of course, you wish to test to breakdown. Even a slight knee in the curve may be an indication of imminent breakdown.

16. This step by step raising of voltage and plotting of current should be continued until the maximum test voltage previously selected is reached. If a current versus time plot is also desired, the time should be noted immediately upon reaching the final voltage step. Then, as the current slowly decays, readings of current and time should be taken at suitable increments and the current versus time curve may be plotted as shown in Figure 3. For a safe insulation system, this curve should indicate a continuous decrease in leakage current with time until such time as the current stabilizes. At no time during this part of the test should there be any increase in current (Figs. 2 and 4).

17. At the end of the HYPOT test, move the high voltage lever switch to the OFF position; allow the material being tested to discharge either through the internal discharge circuit of the HYPOT or by using a hot stick and rubber gloves and grounding the output.

18. **The kilovoltmeter on the HYPOT will give a direct indication of the voltage at the output terminal regardless of whether the HYPOT is on or**

off. The cable or equipment being tested should not be touched until the kilovoltmeter reads zero.

19. After the kilovoltmeter reads zero, disconnect all test leads and immediately again connect all cable conductors or equipment terminals to ground and leave grounded. It should be noted that rubber gloves must be worn at all times during this portion of the test, as the dielectric absorption effect in cable in particular, and to some extent in rotating equipment, will tend to restore a dangerous voltage on the disconnected item until it has been adequately grounded for a considerable length of time.

20. The other phases of a multi-phase installation may next be tested in a similar manner.

21. In many cases, once the fault occurs, its exact location may be determined without too much difficulty. However, in those cases where a fault occurs in a long run of cable, special fault finding techniques incorporating the ARI Thumper could be of great assistance. Use of the ARI Thumper Cable Fault Locator is described in a later section.

• SECTION 9

Go, No-Go HYPOTTING

The tests described above give good indications of the condition, and with proper interpretation may even allow prediction of the expected life of the equipment or cable. But to do the job properly takes time and a certain amount of experience and skill, both in conducting and evaluating the operation.

A much shorter and simpler test may be sufficient in those cases where the contractor, purchaser or operator is only interested in knowing whether or not the installation meets a specific high voltage breakdown requirement. That is, will the equipment or cable withstand "X" kilovolts without breakdown.

The procedure to be followed in conducting this Go, No-Go HYPOT test is:

1. Set the microammeter range switch to the highest range.

2. Gradually raise the test voltage at a rate which will keep the charging current below the microammeter full scale point. The voltage is raised at this steady rate until the required test value is reached.

3. Maintain the voltage at this value for the length of time required by the specification, or in the absence of any specification, until after the current has stabilized for a minute or more.

4. If the leakage current does not become excessive (remains below the maximum specified value or is low enough to avoid tripping circuit breaker), the equipment passed the test.

5. Failure is indicated by a gradual or abrupt increase of current, sufficient to trip the circuit breaker. It should be noted that this high leakage current should not be confused with a high charging current. High charging current may be minimized by raising the voltage at a slower rate.

6. If the current seems to be rising too high, stop raising the voltage at that point and wait. If the current immediately starts decreasing, the indication is that of charging current, and the test may be continued.

7. If the current holds steady or increases, it is either due to leakage current or to corona current. Methods of minimizing the effect of corona current are explained in Sections 6 and 7.

8. At the end of test, reduce voltage to zero and follow procedure given in Section 8, Steps 17 to 20.

This type of test is not by any means a thorough analysis of cable condition. However, it is a sufficient test and all that is necessary in a great number of cases. For example, the contractor installing the cable must immediately know if the cable and the installation is good. If it is defective, this test will reveal it in the shortest possible time. If the cable or the installation is not good, the test cannot harm it any further and the contractor may proceed to make the necessary repairs. The only information sought in this type of test is that the cable will not break down below a required test voltage level.

When applicable, this type of test will save many hours of test time and its usefulness should not be overlooked.

• SECTION 10

Insulation Resistance Measurements

The DC HYPOT is an invaluable tool for making insulation resistance measurements at higher voltages. Using the same connections and following the same precautions given for high potential testing, raise the voltage to the desired value, and read the microammeter after the current has stabilized (no further decay). Insulation resistance may then be calculated

using Ohm's law:

$R = E/I$

Where R is the insulation resistance in megohms
E is the voltage
(KV meter reading $\times$ 1000)
I is the current in microamperes
(microammeter reading)

The insulation resistance may be calculated at each voltage step as the leakage current versus voltage test is made. Curves of insulation resistance versus voltage will yield much information to the experienced operator. It also helps to keep records of insulation resistance at a specific voltage so that they can be compared from test to test or from year to year. This will give a good basis of comparison for proper insulation evaluation.

Insulation resistance may also be measured with standard ARI VIBROTESTS. These instruments will give a direct reading of insulation resistance at a 500 volt (or higher, depending on the model) test potential. The use of this instrument should not be confused with a high potential test, since insulation resistance, in general, has little or no direct relationship to dielectric or breakdown strength. For example, an actual void in the insulation may show an exceedingly high value of insulation resistance even though it would permit breakdown at a relatively low voltage. Insulation resistance measurements using the VIBROTEST are of help in determining whether or not the items under test are even suitable for hypotting.

If the insulation resistance is abnormally low, the material is defective and there is no need to make the HYPOT test. If the insulation resistance is high, then the HYPOT test could be made.

Instead of waiting for the current to stabilize before calculating the insulation resistance, readings of voltage and current can be taken at fixed time intervals during the leakage current versus time test, and calculations made of insulation resistance as a function of time. A plot of the insulation resistance versus time is known as the absorption curve and is often used when testing rotating machinery. In a good insulation system, this curve will rise rapidly at first (because of the decaying charging current) and gradually level off (an indication of stabilization of leakage current). The more pronounced the rise, the better the insulation. A relatively flat curve will indicate a moist or dirty insulation.

The ratio of the insulation resistance at the end of ten minutes to the insulation resistance at the end of one minute is called the polarization index. If the value of polarization index is less than two, it is usually an indication of excessive moisture or contamination. Values as high as ten or more are commonly expected when testing large motors or generators.

Caution should be exercised in evaluating the importance of insulation resistance measurements. The absolute value is not critical, but the relative order of magnitude, or the change in value as the test progresses, is significant. Such factors as temperature, humidity, etc. can have a very large effect on the reading.

• SECTION 11

Cable Fault Locating Using the ARI Thumper

A fault which develops in a power cable will generally fall into two classifications: (1) high resistance faults or (2) dead short or low resistance faults. The high resistance fault is the most common and usually consists of a break or gap in the insulation. This, in effect, causes a high resistance to develop between conductors in the cable or between a conductor and the outer shielding or casing of the cable. The low resistance fault is essentially the same except that the conductors in question may actually be in physical contact with the outer shielding or casing or with each other; or, the high resistance fault may come in contact with water. Either of these two types of faults may be located with the use of the Thumper. The principle of fault location is simple and is essentially the following. A high DC voltage is applied to a capacitor, which will charge to a predetermined value, as established by the setting of an adjustable sphere gap. The cable under test is in series with the sphere gap and capacitor. When the voltage in the gap reaches the preset value, the capacitor instantaneously discharges across the gap and a pulse of energy with a very steep wave front is sent down the cable to bombard the fault. If the potential of the pulse is of sufficient magnitude, it will break across the fault and return to the low side of the capacitor. If the pulse is not of sufficient magnitude to break down the fault, the arc current will merely serve to charge the cable capacitance.

The voltage of the energy pulse may be increased by increasing the sphere gap setting until the voltage becomes of sufficient magnitude to break down the fault. The maximum voltage applied to the cable is limited by the adjustment of the gap, and the minimum voltage is determined by the resistance of the fault.

In most cases, when the energy pulse flashes across the fault, there is a loud audible report which will reveal its exact location. It is only necessary, therefore, to traverse the route of the cable and listen for the fault to reveal itself. In the case of a dead short or where other conditions limit noise, a pickup coil with suitable indicating device or earphones may be used (see Section 13).

• SECTION 12

Connecting and Using the Model 8501 Thumper

The ARI Thumper Cable Fault Locator converts the high voltage, low current output of a DC high potential tester into a high voltage, high current impulse supply. It consists primarily of a high capacitance high voltage capacitor, two sphere gaps, necessary current limiting resistors and terminations for connecting the unit between the high potential supply and the cable under test. One sphere gap is adjustable from the outside of the unit so that the breakdown voltage may be varied to suit the fault in the cable. By proper adjustment of the gap spacing and the voltage setting of the high potential supply, the test potential and repetition rate of the pulse voltage may be varied to suit conditions. The Thumper is also equipped with a fixed safety gap to prevent overcharging of the capacitor. The safety gap will discharge the capacitor at approximately 25 KV.

Connections:

1. Prepare the cable to be tested in accordance with all safety rules, disconnecting both ends and tagging to protect other personnel. Disconnect all arresters which might form paths for flashover from the Thumper output; disconnect all transformers and other devices which might be regarded as paths of low resistance or high capacitance.

2. Make sure that the output of the high potential test set is at zero volts, and take all necessary safety precautions to prevent accidental application of high voltage. Make sure also that the grounding switch on top of the Thumper is in the grounding (down) position. This switch must be activated with a *sharp* push or pull.

3. If the Thumper is being used with an ARI DC HYPOT (models with output voltages of 45 KV to 120 KV at 5 or 10 MA capacity are recommended), connect the Thumper to the HYPOT as follows (see Figure 17):

   A. Plug the Thumper input cable into the HYPOT output receptacle and connect the shield grounding strap to HYPOT safety ground terminal. Connect Thumper ground terminal to the HYPOT ground terminal and place panel switch in the METERED RETURN position.

   B. If a high potential test set other than an ARI HYPOT is being used, connect the high voltage input cable from the Thumper to the HV out-

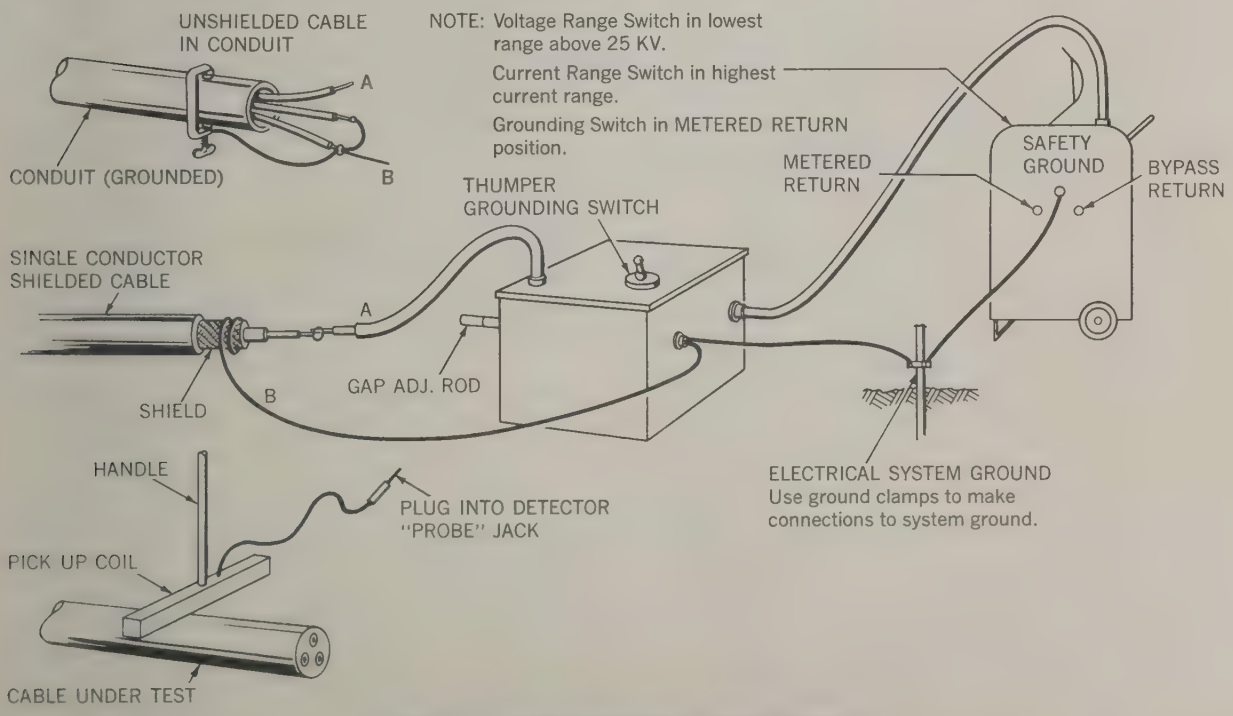


Figure 17. Thumper Connections for Fault Location

put termination of the test set and connect the Thumper ground terminal to the test set ground.

4. Make Thumper connection to the faulty cable by connecting the cable conductor to the Thumper output lead and the cable shield or casing to the Thumper ground terminals.

Operation:

1. Pull grounding switch up to operating position.

2. Set the gap to the $\frac{1}{16}$" mark.

   NOTE: The lucite shaft which extends from the Thumper is calibrated in sixteenths of an inch. When the ring on the shaft coincides with the cabinet edge, there is no gap at all (spheres touching). Each red mark that is passed as the shaft is turned counter-clockwise represents $\frac{1}{16}$" of gap opening. There is a maximum of $\frac{1}{4}$" gap opening. The fourth mark therefore represents the maximum setting of the gap.

3. Set the HYPOT to the highest current range and the lowest voltage range over 25 KV. Increase voltage slowly until sphere gap breakdown is heard.

4. If the gap is adjusted so that there is not enough energy to break down the fault, the Thumper will continue to charge until the safety gap breaks down. When this occurs the circuit breaker in the HYPOT may trip, or the Thumper may merely repeat the charge and discharge cycle across the safety gap. Breakdown across the safety gap can be distinguished from breakdown across the adjustable gap by the loudness of the report. The safety gap will break down with a dull snap while the adjustable gap breakdown noise is sharper and louder.

   NOTE: Due to distributed capacitance in the cable under test, there may be a very small arc between the center sphere and the adjustable sphere at small gap settings. This small arc current is merely serving to charge the distributed capacitance in the test cable and is not breaking across the fault if the safety gap ultimately breaks down. When it is determined that the gap setting is too small, it should be increased and the voltage applied once more.

5. When the fault does break down, there will be a loud report from the Thumper and the arc will occur between the center and adjustable spheres.

6. The HYPOT voltage should be adjusted so that the output current does not exceed the maximum rating of the test set. If too much current is drawn the HYPOT circuit breaker will operate.

7. When the fault has been broken down, the discharge repetition rate may be increased to approximately 20 per minute by decreasing the gap setting to approximately $\frac{1}{16}$" and adjusting the voltage and current input as high as possible without causing the HYPOT circuit breaker to trip.

8. The fault in the cable may then be located by the methods described in Sections 11 or 13.

9. Before connecting or disconnecting the test cable from the Thumper, ALWAYS ground the Thumper and the test cable. This is done by pushing down sharply on the grounding switch located on the top of the Thumper. Always leave the grounding switch in the grounding position when Thumper is not in use. The kilovoltmeter should indicate zero volts before any high voltage connections are touched.

10. Always ground the cable that has been removed from test to eliminate the possibility of dangerous voltages due to build-up through the cable effective capacitance. The build-up is slow and may reach its maximum after a period of several hours. After the cable has been discharged, upon immediate removal of the test equipment, the discharge voltage is at its lowest ebb, but the cable still should be handled with rubber gloves while connecting the equipment.

• SECTION 13

Using a Thumper Detector

When the faulted cable is damp, completely shorted, or deeply buried, an audible report may be difficult to locate or may not even be heard. Under these conditions, the signal radiated along the cable by the thumping may be picked up with a sensitive electronic device or Thumper Detector.

The ARI Thumper Detector consists of a self-contained (battery powered) transistorized amplifier and visual detector, a ferrite pick up probe with detachable handle, and a short length of interconnecting cable. When not in use, the probe and cable are stored in a special compartment of the detector case. To put the unit in use, the probe is removed, the handle is fastened, and the cord plug is inserted into the panel jack on the detector itself. The detector is supplied with a neck strap so that it may be carried

by the operator leaving his hands free to handle the probe.

Since the signal radiated by the cable under test will vary greatly depending upon the type of cable, type of fault, distance under ground, breakdown voltage, etc., it is impossible to outline specific detection instructions suitable for every occasion. However, the following general procedure will give satisfactory results in the majority of cases.

Adjust the HYPOT and Thumper so that discharge occurs every few seconds. Place the probe on the ground a few feet from the Thumper with its axis at right angles to the path of the cable. Each time the Thumper discharges, the pointer of the detector indicator will jump. Adjust the panel control for ⅓ to ½ scale deflection. As the probe is rotated, it will be noted that the signal will usually be strongest when the probe is at right angles to the cable and will disappear or diminish when the probe is parallel to the cable. The signal will also disappear when the probe is moved a few feet off the cable path. By holding the probe so that the signal is maximum, cable path may be easily followed.

As the cable path is followed, the signal will gradually diminish with distance from the Thumper. The control on the detector should be adjusted when necessary to maintain an easily readable indication. There will be a sudden drop off or complete disappearance of the signal in the vicinity of the fault. When the fault has been passed, the signal may reappear. In the immediate vicinity of the fault, the signal may be brought back by rotating the probe at right angles to the previously held position, though this is not always the case.

A splice or tap on the cable will also cause a change in the signal strength, but this should not be confused with a fault. At a tap, the signal will usually not disappear with rotation of the probe, and the signal will also follow the path of the tap. When there are other cables in the same trench or conduit, the adjacent cables may carry the signal past the fault. However, a decided change in signal level should be noted when the fault is passed.

• SECTION 14

Safety

Regardless of the precautions and the safety features built into the equipment, HV testing has a certain element of danger. It is therefore essential that the operator follow all accepted safety practices, proceed with caution, and in general, do all in his power to assure a safe test.

It is essential that the high potential test set be properly designed and manufactured to permit testing without unduly endangering personnel. To this end, all ASSOCIATED RESEARCH, INCORPORATED HYPOTS contain many safety features, a few of which are listed below.

1. Zero return interlock—which requires that the voltage control be set at zero before high voltage can be applied. With this system, accidently hitting the HV ON switch will not energize the output.

2. Three wire input line cord with ground clip to enable the machine to be grounded right to the conduit.

3. Fast-acting secondary circuit breaker, in addition to a primary overload breaker: immediately shuts off high voltage in case of a fault.

4. Kilovoltmeter connected directly to the output so that its reading at all times gives a true indication of the voltage at the terminal, whether the machine is turned on or off.

5. Internal bleeder to reduce the charging current to zero after high voltage is turned off.

6. Connections for external interlock so that the high voltage controls can be disabled with an external safety switch.

7. Shatter-proof plastic faced meters.

8. Cabinet and all touchable parts of the HYPOT (with the exception of the high voltage output, of course) are at ground potential. This includes all controls, meter faces, exposed terminals, etc.

The operator is responsible for the safety of all personnel while using the equipment. Do not attempt to disconnect any item under test while the instrument high voltage is energized. Keep all personnel a safe distance from the high voltage output when making tests.

• SECTION 15

Example of a Test Made on a 13.8 KV, 75,000 KVA, 60 Cycle Generator

As a regular bi-annual maintenance test at one of the large power companies, the generators are opened for inspection, the rotors removed and the stator winding insulation tested. The procedure and data presented here is typical of one such test.

This particular company determined the maximum test voltage by means of the formula

$E_T = (2E_N + 1000) \times 1.6 \times .6$

Where E_T is maximum test voltage

E_N is nameplate voltage

1.6 is the AC to DC test conversion factor used by this company

.6 is the derating factor used by this company to take account of the fact that this is a maintenance test on a piece of older equipment.

For this test

$E_T = (2 \times 13{,}800 + 1000) \times 1.6 \times .6 = 27{,}400$ volts or 27.4 KV

The HYPOT used in this test was an ARI Model 5265 mobile DC HYPOT, with voltage ranges of 0-15/30/45 KV and current ranges of 0-50/250/2500 microamperes.

To reach the value of 27.4 KV in about eight to ten steps, a three kilovolt increment was chosen. This permits good reading on the 30 KV range of the instrument (three scale divisions per increment) and easy plotting. Past experience had shown that the expected leakage current would be in the neighborhood of 30 to 40 microamperes. A sheet of graph paper was therefore prepared, as shown in Figure 18. The stator winding was to be tested single phase to ground with all windings not under test grounded, so the connections to the HYPOT were made as shown in Figure 12.

The HYPOT KV meter range switch was set to the 30 KV position and the current range switch to the 2500 microamps position.

The high voltage switch was turned on and the voltage slowly raised to the 3 KV point. The rate of rise was slow enough to keep the charging current below the value that would drive the microammeter off scale or trip the circuit breaker.

When the 3 KV point was reached, the time was noted. Then, as the initial high charging current slowly decayed, the microammeter range switch was progressively turned to the 250, then the 50 microampere position. When the current stopped decaying, the time interval was noted; 2½ minutes in this case. Three minutes was then chosen as the current stabilization period.

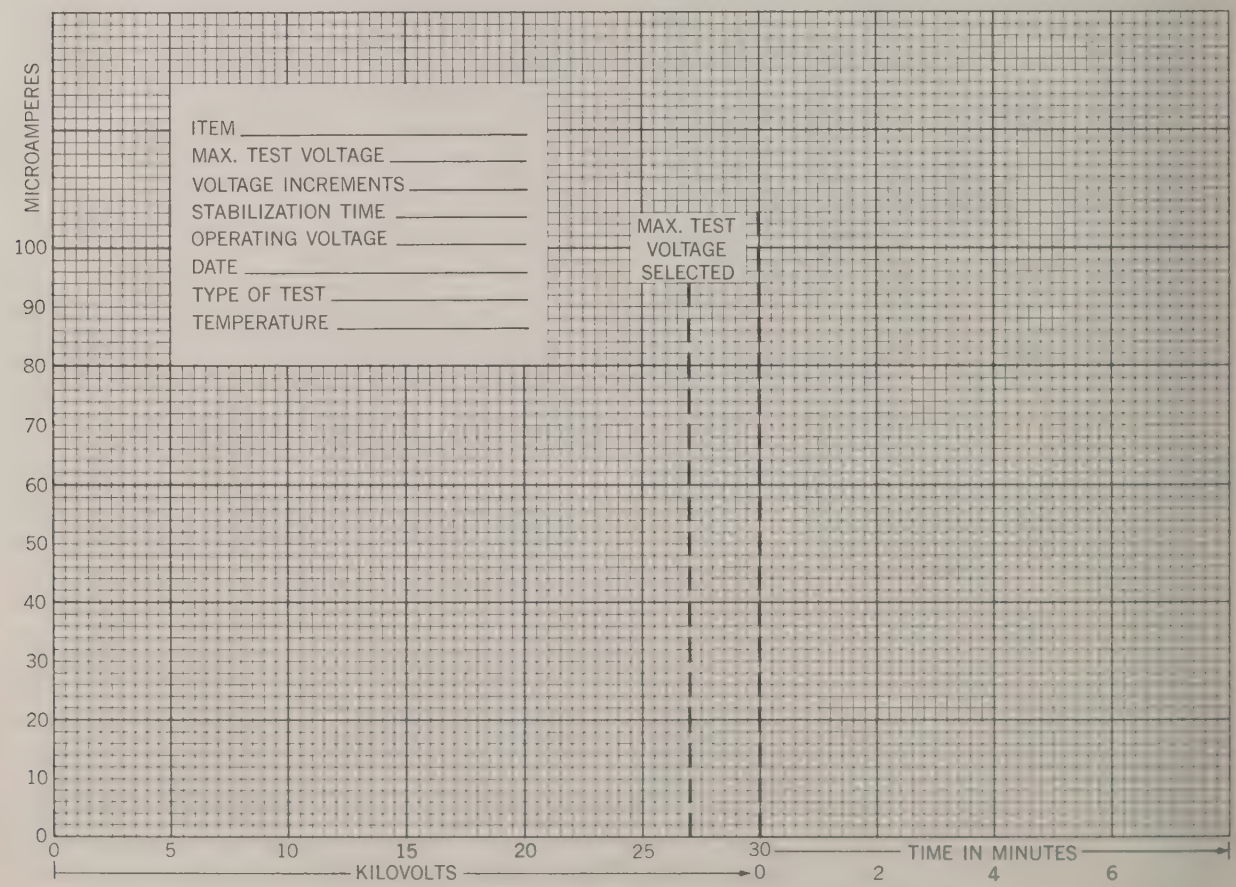


Figure 18. Preparation of Graph Paper for DC HYPOT Test of Generator

The microammeter range switch was then turned back to 2500 microamp position and the voltage raised to 6000 volts. As the current flow decayed, the microammeter range switch was again progressively lowered through the 250 microamp to the 50 microamp position, and at the end of three minutes the current reading was taken and added to the leakage current versus voltage graph.

The microammeter range switch was then turned back to 2500 microamp position and the voltage slowly raised to 9 KV. The current reading was then taken at the end of three minutes and plotted as before. Since the plot of current versus voltage remained relatively straight, the process was repeated until 27 KV was reached, raising the voltage in three KV increments and taking the current reading at the end of three minutes stabilization time. Results of this test are shown in Figure 19.

When the 27 KV point was reached, voltage was maintained and readings of current were then taken at one minute intervals for ten minutes to give a plot of current versus time. This plot (Figure 19) shows a steady decrease of current until the stabilized value was reached. After the stabilized value was reached, the current remained relatively steady, which is an indication of good condition of insulation.

The voltage was then decreased to zero, and phase one was grounded after the HYPOT voltmeter indicated zero. Phase two was then ungrounded and connected to the HYPOT output and tested in a manner exactly similar to phase one, with similar results. The test was then repeated for phase three. Here, however, it is noted that the current versus voltage curve appeared to climb faster when 21,000 volts was reached. It was decided at this point to decrease the increment of voltage so that definite indication of the knee of the curve could be spotted before breakdown. Results of the current reading at 22,000 and 23,000 volts showed a definite upward swing (Figure 20). It was decided to continue the test until breakdown, since this would be a very convenient time to repair and rewind the stator, if necessary, since the unit was out of service already. The test was carried on, continuing in 1000 volt increments, until breakdown occurred slightly below 25,000 volts (Figure 20).

Because of age of the machine, it was decided to

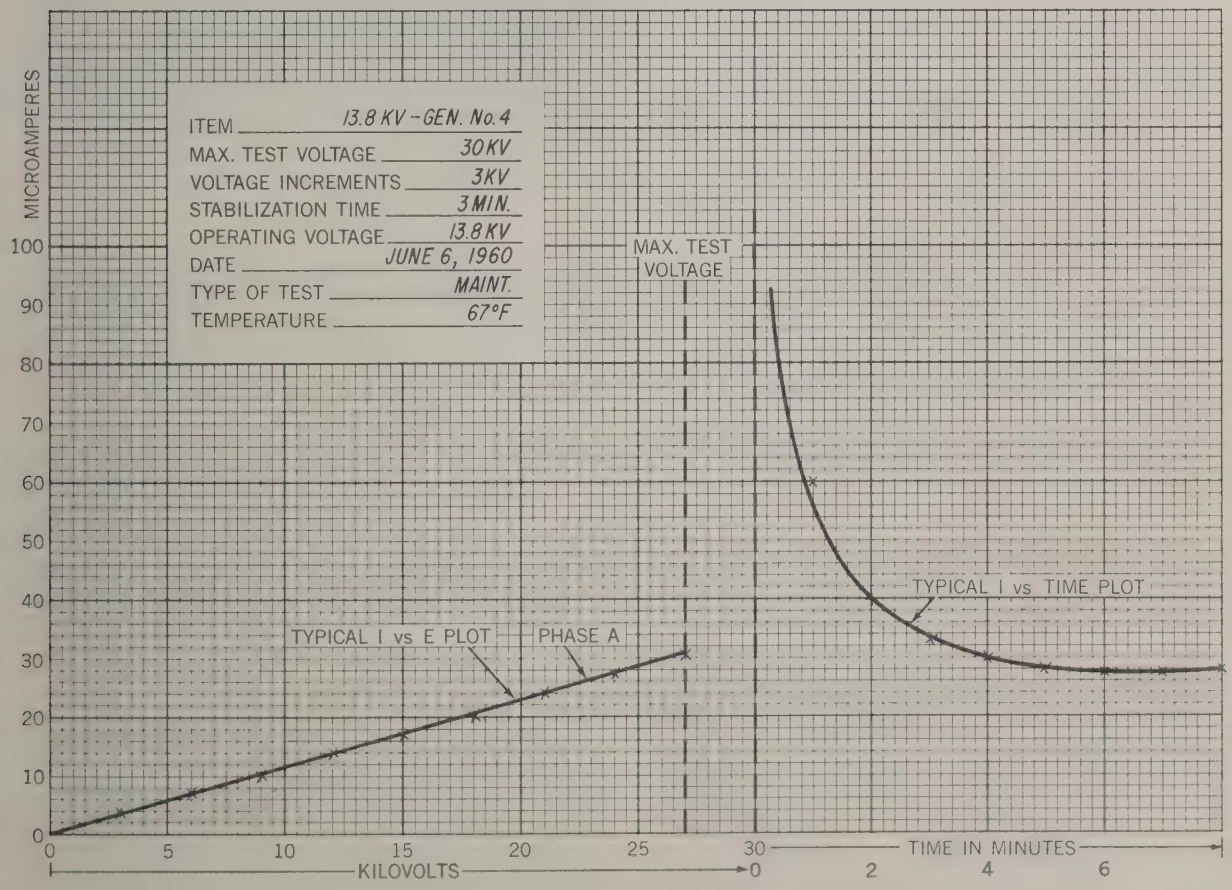


Figure 19. DC HYPOT Test, Phase A

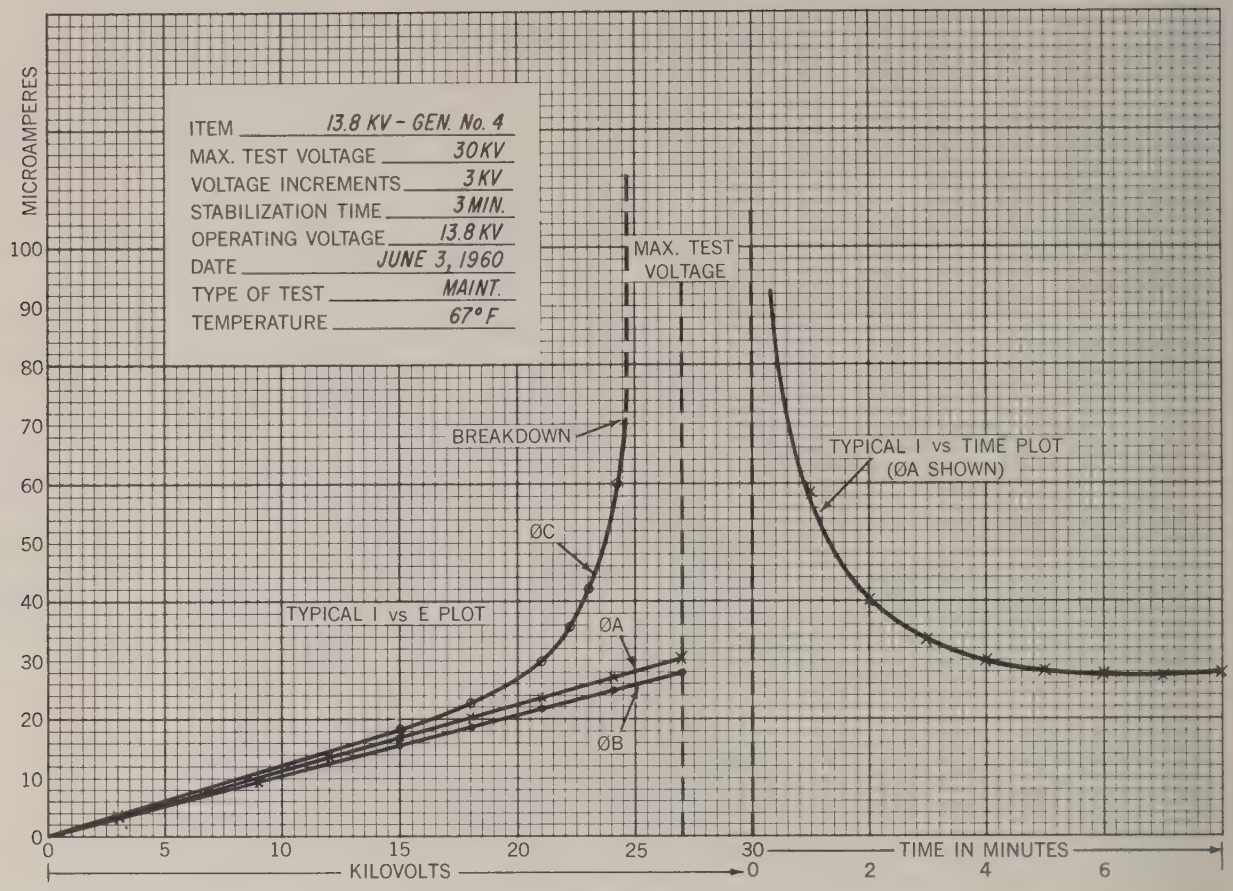


Figure 20. DC HYPOT Test, Phase A, B, C

rewind the whole unit. After rewinding, the DC high potential test was repeated with the results shown in Figure 21. The results of the test taken prior to rewinding are also shown (dotted) in the same figure. It can be seen that the rewinding and reinsulation improved the insulation resistance, and that the leakage current, while following the same general curve, was lower after the servicing than before.

• SECTION 16

Example of a Test Made on a 5 KV Cable Installation

The test described here is similar to an acceptance test made by a construction firm on a new installation of 5 KV Ozone resistant rubber cable. This cable had a factory AC test voltage of 14 KV specified.

The HYPOT used to perform this test was an ARI Model 5480M1 mobile DC HYPOT, with voltmeter ranges of 0-25/50/75 KV and microammeter ranges of 0-5/50/500/5000 microamps. It is noted that in cable testing especially, where a very low leakage current may be expected, a HYPOT with a special low range of just a few microamps makes it particularly easy to read the low values of leakage current involved.

Since this is an acceptance test, the formula used by this particular firm to determine the maximum test voltage was

$E_T = E_F \times .8 \times 3$

where E_T = maximum test voltage
E_F = cable manufacturer's recommended factory AC test voltage
.8 = conversion factor for derating from factory testing to acceptance testing
3 = AC to DC test conversion factor used by this particular company for this particular cable.

In this case

$E_T = 14 \times .8 \times 3 = 33.6$ KV DC.

Since the closest higher voltage range on the HYPOT was 0-50 KV, it was decided to raise the voltage in steps of 5000 volts. This gives very readable points on the 50 KV meter range (five scale divisions) and permits seven increments up to 35 KV DC. Of course, eleven increments of 3000 volts or other values could

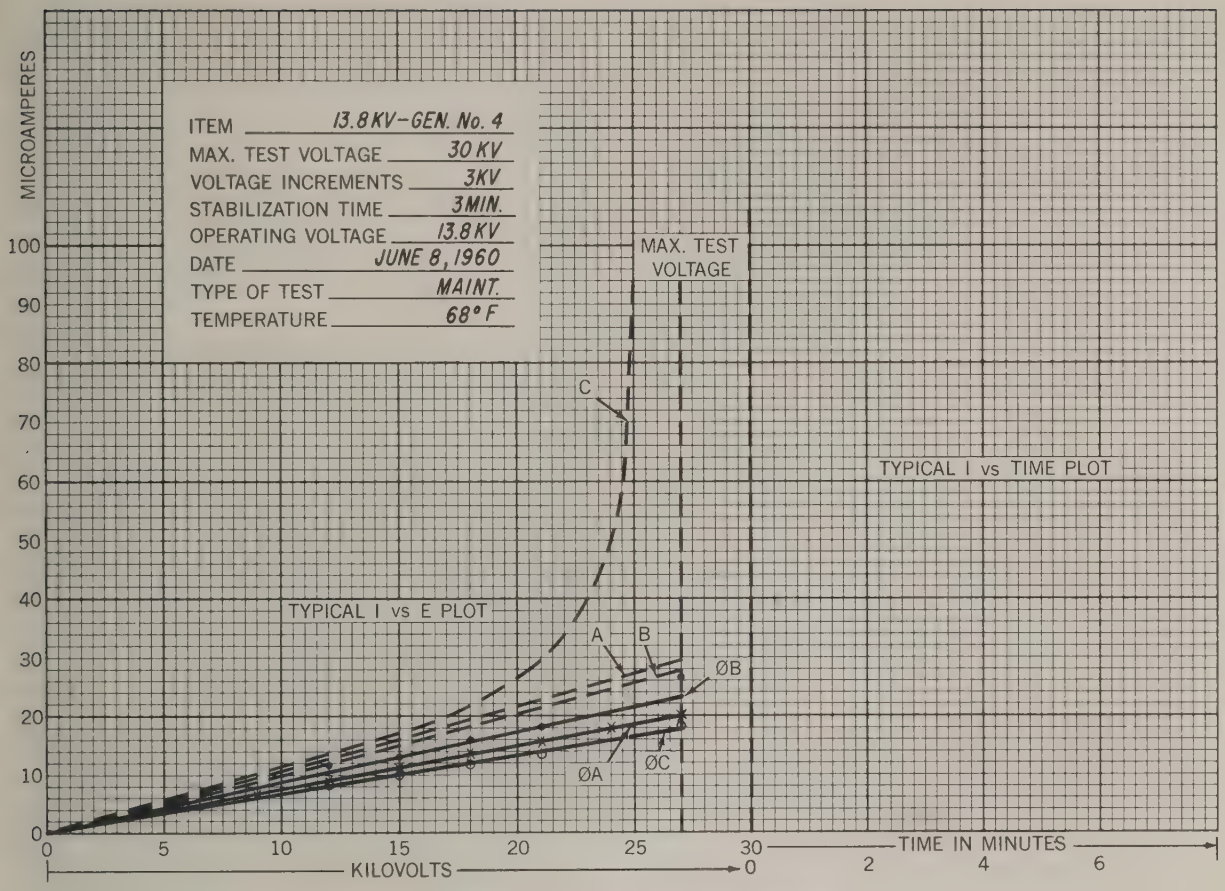


Figure 21. DC HYPOT Test After Rewinding

have been chosen, depending upon the preference of the operator.

Connections were made as shown in Figure 13. It is noted that the proper use was made of corona ring and bypass return terminal to permit accurate readings of the low leakage currents expected. It is almost always necessary to take special precautions when using current ranges as low as the 5 microamp range that would be used in this test. Knowing from past experience that this type of cable should exhibit leakage currents of only a few microamps, the graph paper for the current versus voltage test was prepared as shown in Figure 22. The operating procedure, similar to that outlined in Section 15, was followed with the KV meter range switch on the 50 KV range and the microampere switch initially set to 5000 microamps. Note that the kilovoltmeter range switch may not be turned during a test, as the internal HYPOT interlocks will shut off high voltage if it were. However, the microammeter range switch may be changed at will.

When everything was in readiness, the voltage was slowly raised to 5 KV at such a speed that the maximum current range of the HYPOT was not exceeded. This could normally take somewhere around five or ten seconds or more. As the initial charging current decayed, the microammeter was progressively switched to lower ranges. During this step, preliminary readings of current versus time were taken to determine the stabilization period required.

Since, in this case, the current settled down to its minimum value at the end of about fifty seconds, a one minute stabilization time was decided upon. The voltage and current at the first step were then plotted, the microammeter range switch returned to the 5000 microampere position, and the voltage slowly raised to 10,000 volts. At the end of the one minute period a reading was taken and the values of current and voltage for 10,000 volts were plotted. The microammeter was again switched back to the 5000 microamp range and the voltage slowly raised to 15,000 volts where the above process was repeated. This was continued until the final test voltage of 35,000 volts was reached. Then current readings were taken every thirty seconds for a five minute period to yield a current versus time curve. Results of the test are shown in Figure 23.

At the end of the five minute current versus time test, the HV switch was turned off, voltage control returned to zero and the current allowed to decay by discharging through the internal HYPOT circuit for several minutes. The remaining charge in the cable was then grounded using a hot stick and rubber gloves. Still using rubber gloves, Phase A was disconnected from the HYPOT and permanently grounded for the remainder of the test. Phase B was connected to the HYPOT in its place. The test was then repeated for Phase B. At the completion of the test for Phase B, the process was repeated for Phase C. Results of all three tests are shown in Figure 23.

• SECTION 17

Selection of the Proper Size High Potential Test Set

With the current emphasis on high potential DC testing, it is important that the anticipated as well as immediate requirements be considered in selecting the proper DC HYPOT. As a rough guide, it is suggested that the maximum voltage range be at least 10% to 25% higher than the maximum test voltage needed. If much testing is to be carried on at lower voltages, it might be desirable to get a multi-range unit. Multiple range HYPOTS usually would have full scale voltage ranges of one-third, two-thirds and full voltage, or one-fourth, one-half and full voltage.

Since HYPOTS with maximum current ranges of from 100 microamps to 25 milliamps or more are available, the selection will be influenced by the maximum leakage and charging currents to be handled. The minimum values of leakage current must also be known in order to select the proper low microampere ranges. If the minimum acceptable insulation resistance is known, and the test voltage is known, the leakage current expected can be calculated by using Ohm's law I = E/R. With E in volts, and R in megohms, the answer will come out in microamperes. The HYPOT chosen should have current ranges that will enable the expected leakage values to be read conveniently. As a rough rule, the lowest microammeter range should be not much more than four or five times the value of leakage current of interest.

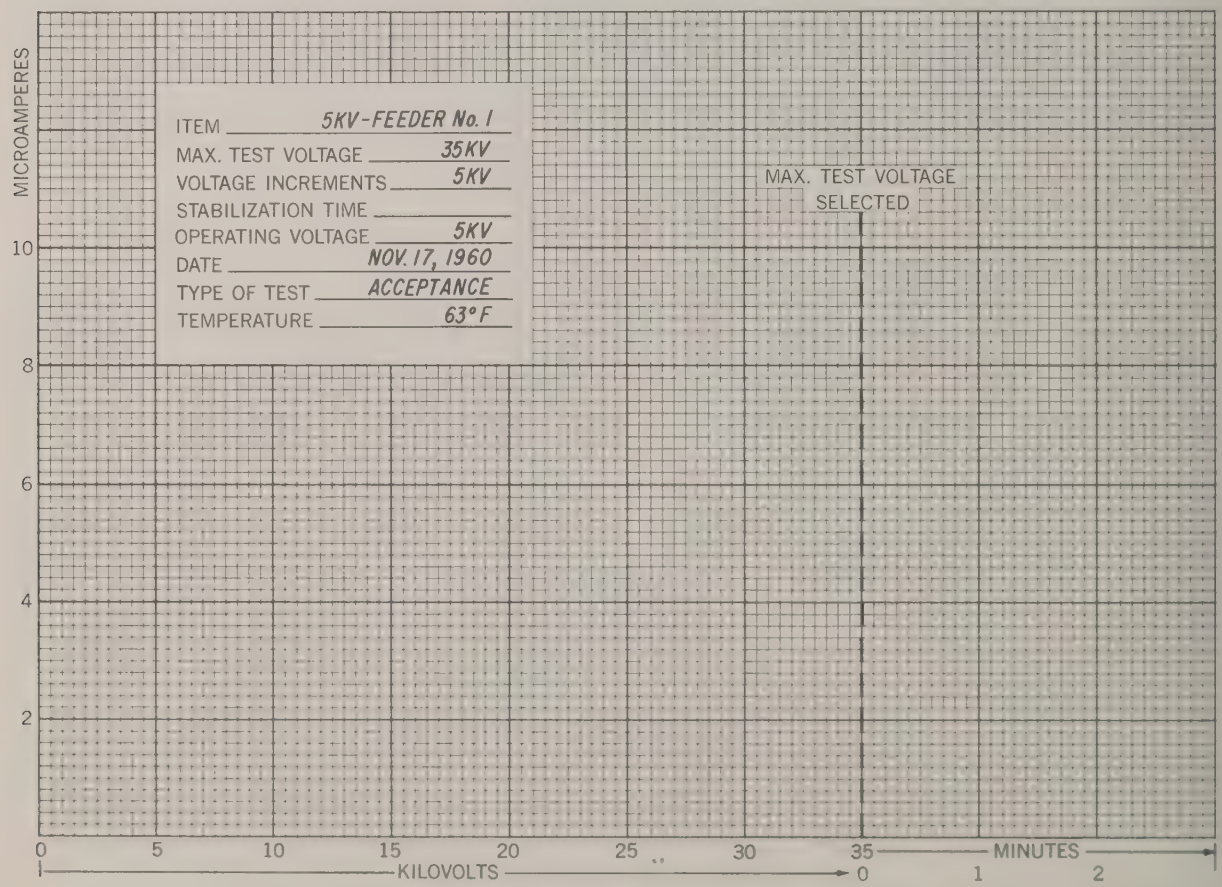


Figure 22. Preparation of Graph Paper for DC HYPOT Test of Scale

The highest current range of the HYPOT will determine the length of time it takes to charge the item under test, since the higher the maximum current rating, the faster the voltage can be raised without exceeding the setting of the overload circuit breaker. In general, a 2½ milliampere HYPOT is adequate for most cable and rotating machinery applications. When a HYPOT is to be used with a Thumper, a higher capacity machine, either 5 or 10 milliamps, is recommended so that more rapid thumping may be accomplished.

The following typical test values from actual cases are given to indicate the order of magnitude of leakage current in some good equipment.

1. 2400 volt, 451 ampere, 1500 kilowatt alternator with Class A varnished cambric insulation and eighteen years of service. On this machine the stabilization time for leakage current was approximately five minutes. Leakage current at 5000 volts test potential was about 2 microamperes.
2. 205,000 KVA, 20,000 volts, 3 phase generator. Typical leakage current for this machine was 400 microamperes at 40 KV test potential.
3. 5 KV, 3 conductor rubber insulated, Neoprene jacketed portable mine power cable. Leakage current at 30 KV was 2½ microamperes.
4. 6600 volts, 15,000 KVA alternator stator. Leakage current at 33 KV was 25 microamperes.

• SECTION 18

General Notes

The values of voltage and current given, as well as the formulas used in determining the maximum test voltages are typical but vary widely from equipment to equipment, from test facility to test facility, and operator to operator. In any case, the final authority for determining the values is the purchaser or owner of the equipment being tested.

The value of factory test voltages is usually available from the original manufacturer of the equipment. Many of the handbooks and catalogs supplied by cable and equipment manufacturers and many of

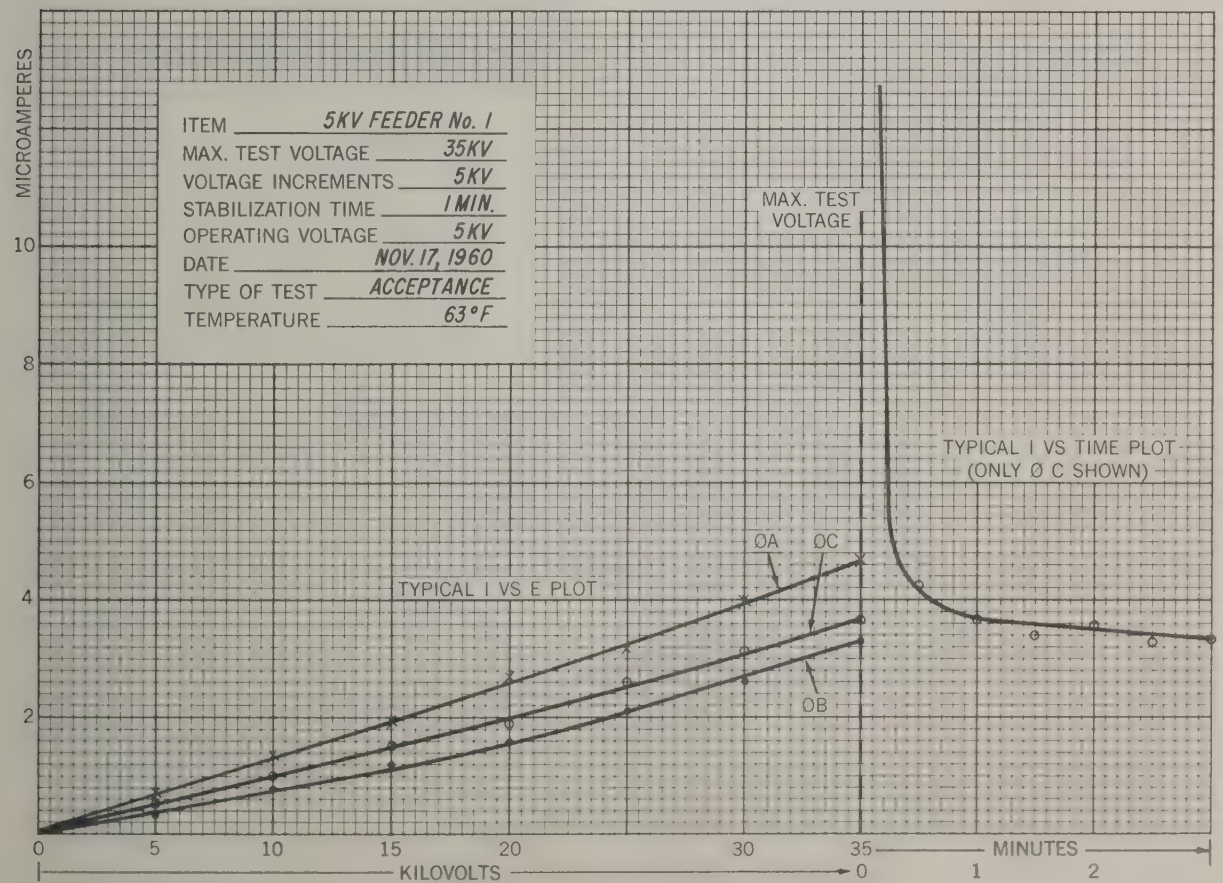


Figure 23. DC HYPOT Test, 3 Phase Cable

the equipment specifications give recommendations regarding the test voltage to be used (see Bibliography, Section 20).

AC to DC conversion factors (the value of DC test voltage to use when the AC test voltage is given) ranging from as low as one to one to as high as four to one are given in the literature. A value of 1.8 to 1 (i.e., DC test voltage = 1.8 × AC test voltage) is quite common.

The maximum test voltage to be used in maintenance, acceptance or proof tests varies widely. However, a figure commonly used in maintenance testing of relatively new equipment is twice operating voltage plus 1000 for AC tests. For DC testing (as discussed here) this figure is multiplied by the AC to DC conversion factor (possibly 1.6 or 1.8). This voltage is then derated to 60% or 80% for older equipment. Hence, a commonly used formula for maintenance testing of older equipment is (as described in Section 15):

$$E_T = (2E_N + 1000) \times 1.6 \times .6$$

However, many organizations use lower values and many use higher values.

Whether a test is carried on to the breakdown point or whether it is stopped prior to, or at the knee of the curve, depends on whether it is more economical to have the outage and make repairs at the time the test is being conducted, or to wait for a more convenient time.

It should be noted that the "knee in the curve" referred to above may be gradual or in some cases may be almost a right angle bend, with breakdown occurring simultaneously with the initial development of the knee. Therefore, it is not always possible to predict the breakdown point in advance.

• SECTION 19

Conclusion

This manual describes only a few of the commonly accepted testing methods and is not intended to specifically recommend these methods in preference to or to the exclusion of others. Exactly what test is made or how it is made depends to a great extent on the experience and desires of the operator or owner of the equipment.

The usefulness and accuracy of DC HYPOT testing is greatly influenced by the operator's experience and intelligent use of the equipment. Careful study of the item under test, in conjunction with a clear understanding of proper connections and precautions, will result in dependable and valuable results.

• SECTION 20

High Potential DC Testing Bibliography

Listed below are a few of the many papers and publications pertaining to the subject of DC high potential testing.

Publications pertaining primarily to Cable Testing:

IPCEA Standard S-19-81—*"Standards for Rubber Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy."* Insulated Power Cable Engineers Association, 283 Valley Road, Montclair, New Jersey.

"The Simplex Manual" gives a full listing of the various industry specifications for wire and cables and the issuing organizations. Simplex Wire and Cable Company, 79 Sidney Street, Cambridge 9, Massachusetts.

IEEE* Paper No. DP 62-532—*"Practical Aspects of Direct Current Testing of Electrical Cables in The Field,"* R. A. Nelson and P. H. Ware.

"DC Testing and Fault Location on 15 KV Primary Distribution Feeders" by Roy A. Nelson, District Engineer, Simplex Wire and Cable Company, 564 West Monroe Street, Chicago 6, Illinois.

Specifications regarding cable testing published by the following: AEIC (Association of Edison Illuminating Companies) 40 West 40th Street, New York 18, New York, NEMA (National Electrical Manufacturers Association), 155 East 44th Street, New York 17, New York.

Publications dealing with DC High Potential Testing of Rotating Machinery:

IEEE Paper Number 43—*"Testing Insulation Resistance of Rotating Machinery, Recommended Practice for"* (Mar. 1961).

IEEE Paper Number 53-31A—*"Techniques and Examples of DC Testing of Rotating Machine Windings"* by C. L. Sidway and B. R. Loxley.

IEEE Transactions Part III, *"Investigation of Maintenance Tests for Generator Insulation,"* C. A. Duke, L. E. Smith, C. A. Roberts, A. W. W. Cameron, (Power Apparatus and Systems) No. 55, August 1961, pp. 471-480.

IEEE Paper No. 56—*"Insulation Maintenance for Large A-C Rotating Machinery, Guide for"* (Feb. 1958).

IEEE Paper No. 95—*"Insulation Testing of Large A-C Rotating Machinery with High Direct Voltage"* (Dec. 1962).

IEEE Paper No. DP 59-511—*"The Use of D-C Overpotential Testing as a Maintenance Tool in the Industrial Plant,"* W. A. Weddendorf

Buships Instruction 9610.19, Serial 660-10042, 2 June 1959, from the Department of the Navy, Bureau of Ships, Washington 25, D.C. Note: This paper authorizes the use of DC high potential testing for all naval shore repair facilities in the maintenance and overhaul of electrical rotating equipment of 5 HP (or KW) and above.

Accident Prevention Bulletin Number 16.03—*"DC Overpotential Testing of Electrical Windings."* Mutual Boiler and Machinery Insurance Company.

Publications of General Interest in the Field of High Voltage Testing:

"Nondestructive High Potential Testing" by Harold N. Miller, Hayden Book Co., Inc., New York, New York, 1964.

"A-C/D-C High Potential Testing" by Harold N. Miller, Associated Research, Incorporated, originally published December, 1961 in ELECTRO-TECHNOLOGY. Reprints available from Associated Research, Incorporated.

IEEE Paper No. DP 63-722 *"AC/DC High Potential Testing—The Advantages of DC for Non-Destructive Insulation Evaluation of Cables and Rotating Machinery"* (1963). Reprints available from Associated Research, Incorporated.

"High Voltage Testing: It Can Be Nondestructive" by Harold N. Miller, Associated Research, Incorporated, originally published February 1, 1961 in ELECTRONIC DESIGN. Reprints available from Associated Research, Incorporated.

"High Potential Dielectric Testing" by J. P. Dallas, H. N. Miller and C. L. Sidway, originally published in INSULATION magazine, March 1, 1961. Reprints available from Associated Research, Incorporated.

IEEE Paper Number 51—*"Guiding Principles for Dielectric Tests."*

IEEE Paper Number 56-176—*"Corrections for Dielectric Absorption in HV DC Insulation Tests"* by F. R. Schleif.

IEEE Paper Number 62—*"Guide for Making Dielectric Measurements in the Field."*

"Economic Gains Dependent Upon Insulation Measurements" by A. W. W. Cameron, B. L. McHenry, M. Kurtz, and D. L. Killam, Ontario Hydro Research, Canada.

*IEEE, The Institute of Electrical and Electronics Engineers, Inc., P.O. Box A, Lenox Hill Station, New York 21, New York.

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APPENDIX

AC/DC High Potential Testing—The Advantages of DC for Non-Destructive Insulation Evaluation of Cables and Rotating Machinery

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Senior Member IEEE
VICE PRESIDENT
Associated Research, Inc., Chicago, Ill.

In spite of the tremendous strides made in the past few decades, insulation is still the weak link in the chain of electrical reliability and the cause of a high percentage of equipment failures. Whether trouble is due to flashover of operating voltage, transients or switching surges, lightning stroke, or excessive leakage caused by aging of the insulation or contamination with dirt or moisture, the need for improved insulation and test methods is emphasized.

In the early days of electricity, insulation tests consisted of hardly more than a 500 volt insulation resistance check. As the inadequacy of this simple test became apparent, procedures involving the application of an over potential of alternating current were developed. As electrical generation and distribution became more wide spread, the size of the equipment and voltages involved grew larger, but the size and complexity of the alternating current test equipment required could not keep pace. A typical large generator or long cable could have such a high phase to phase or phase to ground capacitance that the quadrature or capacitance current required of the test set might be several amperes at the test voltage and an alternating current high potential test set capable of performing a 30 KV test would have to have an output of as much as 75 KVA.

The development of high vacuum and gas rectifiers first made direct current high potential test sets practical, but it was the modern selenium and silicon solid state rectifiers that enabled them to come into their own with units having the high reliability of the alternating current type but considerably smaller and less expensive. In spite of the early head start of the alternating current test sets, the more modern direct current units are assuming an ever more important place in the field and are rapidly taking over whenever equipment of high capacitance must be tested, or where quantitative rather than qualitative results are necessary.

WHY TEST?

Insulation failure in even a properly designed equipment may result from such causes as aging and embrittlement due to evaporation of plasticizers, electrolytic deterioration, chemical deterioration, lowered strength due to the absorption of moisture, physical damage, cold flow which could dangerously reduce what formerly might have been an adequate thickness, gradual damage or tracking due to corona in internal voids or across the surface with eventual breakdown due to transients, or abnormal high voltage stresses. While it is impractical to perform physical tests to pinpoint each of these possible defects, a properly performed over potential test can very frequently point out weaknesses in the insulation regardless of cause.

A high potential test may be made to determine the maximum voltage the equipment or insulation can stand, or to determine if the insulation level is sufficiently high to assure safe operation. The first type of test is normally performed in the laboratory during the initial development of the material or equipment. It is a destructive test but deliberately so; the voltage is intentionally raised until the equipment or insulation fails so that the value of the voltage stress that can be withstood may be learned. The second and more common type of test is non-destructive, made to assure that the insulation level is above a specified value. An experienced operator may not only be able to assess the present condition of the insulation but often can make a good prediction regarding its possible future life.

THE DIELECTRIC CIRCUIT

A high potential test is made between two circuits insulated from each other so that the voltage is actually impressed across an insulating structure. The equivalent circuit of the dielectric may be represented by a capacitor C and resistance R_A in parallel with a resistance R_L as shown in Figure 1. The capacitor represents the electrical capacitance between the two metallic circuits (to which the high voltage and ground return leads of the test set are connected), the resistance R_A represents the absorption losses, while the resistance R_L represents the leakage paths through and over the insulation.

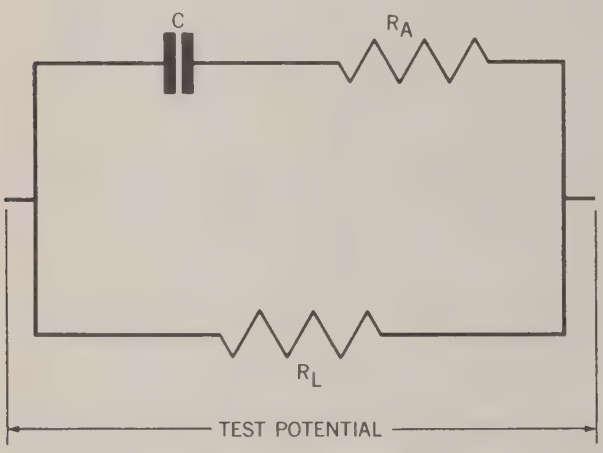

Figure 1. Dielectric Circuit

Alternating Current Components

If an alternating potential were applied across the circuit, the total current (neglecting stray and corona currents) would consist of an out of phase (or quadrature) component (commonly referred to as the capacitance current) through the capacitor, and an in phase (or leakage) component through the resistance R_L. An alternating current test set must supply the vector sum of these two currents. If the item under test is small (low capacitance), the quadrature current may be small compared to the leakage current and may be neglected. If the item under test is large or highly capacitive, the quadrature current could be many times larger than the leakage current and would actually be the critical factor in determining test set size. For example, some modern generators have such a high winding to frame capacitance that the quadrature current at a 25 KV (kilovolt) test potential could reach 3 amperes and the test set would need an output rating of 75 KVA (kilovolt amperes) merely to supply this component.

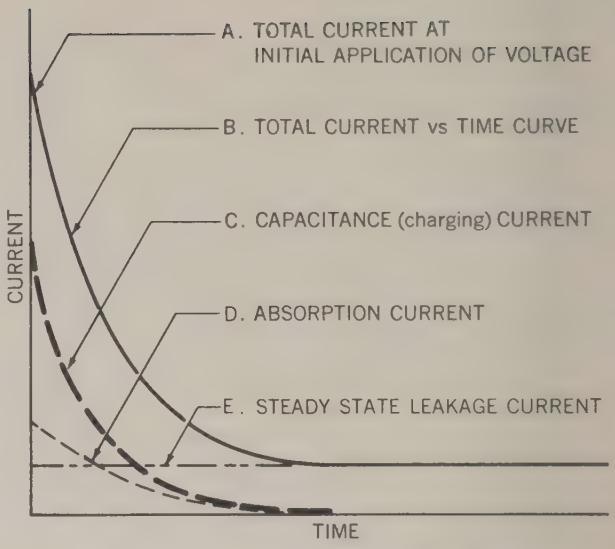
A. TOTAL CURRENT AT INITIAL APPLICATION OF VOLTAGE
B. TOTAL CURRENT vs TIME CURVE
C. CAPACITANCE (charging) CURRENT
D. ABSORPTION CURRENT
E. STEADY STATE LEAKAGE CURRENT
CURRENT
TIME

Figure 2. Current vs Time in a DC High Potential Test

Direct Current Components

If a direct potential were applied across the circuit, the total current flow would be the sum of three components (again neglecting stray and corona currents): (1) the capacitance (or charging) current, (2) the absorption current, and (3) the leakage (or conduction) current (see Figure 2).

The capacitance current starts at an initially high value and exponentially decays toward zero in accordance with the well known equation:

$$I_C = E/R_E{}^{-T}/RC \qquad \left(E/R_E\right)^{-t/\tau}$$

Where I_C is the capacitance current, E is the applied voltage (or change in voltage if it is raised in steps), R is the internal resistance of the test set plus any connected series resistance, T is the time after application of voltage and C is the capacitance of the item under test.

The absorption current is due to the polarizations and accumulation of electrical charges which take place in an imperfect dielectric under the stress of an applied voltage. It also starts at a relatively high value and gradually decays to zero. An empirical equation approximately describing this current is:

$$I_A = AVC_T{}^{-B}$$

Where I_A is the absorption current, A and B are constants depending on the type and condition of the insulation and V is the incremental change in voltage (as the voltage is gradually increased), and T is the time after the change in voltage.

The leakage current depends primarily on the applied voltage and the total series resistance of the circuit as given by Ohm's Law:

$$I_L = E/R_S$$

Where I_L is the leakage current, E is the applied voltage, and R_S is the total series resistance in the direct current circuit (of which the insulation resistance R_L is the major factor).

Since the first two components decrease with time, the current measured after sufficient time has elapsed for conditions to stabilize is the true leakage (or steady state) current.

AC or DC Tests

The above explanation highlights the major factors affecting the use of alternating current or direct current for high potential tests. An alternating current high potential test set of inconveniently large size may be required when equipment or cables of high capacitance is under consideration. The high quadrature current may completely mask even abnormally high leakage currents and obscure the test results. However, if the capacitance is only moderate, the heavy avalanche of current that occurs at breakdown may permit indication of failure by the action of a circuit breaker set slightly above the quadrature current value. There is little difficulty in performing or interpreting an alternating current test on small equipment (low capacitance) where the leakage current is larger than the quadrature current.

In a direct current test, the capacitance will have little or no effect on the steady state value of leakage current but a considerable length of time may be required for the initially high total current to decay so that the steady state leakage value may be measured. The charging current may be kept within reasonable limits by gradually raising the voltage so that the incremental voltage divided by the series resistance yields an initial current within the rating of the test set. By raising the voltage slowly enough even a highly capacitive item may be tested with a unit capable of delivering only a few milliamperes.

TEST SET SIZE

The power rating required of an alternating current high potential test set suitable for testing cables and rotating machinery is largely dependent on the quadrature current:

$$I_C = E_T/X_C = 2\pi F C E_T$$

and

$$VA = I_C E = 2\pi F C E_T E$$

Where I_C is the quadrature current, E_T is the test voltage, X_C is the capacitive reactance of the load, F is the line frequency, C is the capacitance of the load, and VA is the power output at the maximum voltage E of the test set.

To allow an adequate safety margin, the test set should have a power rating about 25% higher than this and a maximum output voltage about 25% above the test voltage; the equation simplifies to (for normal 60 cps line frequency):

$$KVA = 0.377CE^2$$

Where KVA is the recommended maximum power of the test set in kilovolt-amperes, C the load capacitance in microfarads, and E the maximum voltage of the unit in kilovolts.

The size of a direct current high potential test set depends not so much on the capacitance of the load but on the expected leakage current and the amount of time available for testing. The greater the current output the faster the voltage may be raised without having the initial charging current exceed the circuit breaker rating. Experience has shown that a 2.5 milliampere test set is capable of performing satisfactorily even with long lengths of cable or large rotating machinery. As a rough rule of thumb (taking into account such factors as internal impedance of the test set, rectification losses, regulation, etc.), it requires approximately 10 milliamperes per second per kilovolt per microfarad to reach full test voltage, i.e., a 1 microfarad load may be raised to 1 KV in 10 seconds if the high potential test set is capable of delivering 1 milliampere, while a 0.1 microfarad load could be raised to 10 KV in the same length of time.

A direct current test set is commonly rated in terms of maximum output voltage and maximum current. While the maximum current must be high enough to permit rapid charging of highly capacitive loads, it is important that the current meter have low enough ranges so that the leakage current values of interest may be satisfactorily read. In general, the lowest full scale current range should not be more than four or five times the expected leakage current. Full scale ranges as low as 2 or 5 microamperes are common, and a typical unit for cable or rotating machinery testing might have ranges of 0-2.5/25/250/2500 or 0-5/50/500/5000 microamperes.

An alternating current test set is rated in terms of maximum voltage and maximum output in KVA (output voltage in KV times maximum current in amperes). It must be remembered that the power output is directly proportional to the voltage and a 10 KVA test set can only deliver 5 KVA at half voltage.

It is interesting to note that a 120 KV, 5 MA direct current test set weighing only 300 or 400 pounds can do an adequate job of testing 3 phase cable runs commonly encountered in underground distribution systems (several thousand feet long). An equivalent test with alternating current might require a 60 or 75 KV, 25 KVA (or larger) alternating current test set weighing upwards of 2000 pounds.

ADVANTAGES OF AC OR DC TESTING

Advantages of AC

There are many cases where alternating current is preferred for testing. Because of its longer history, a considerable amount of data has been accumulated correlating test results for various equipment. Most specifications require or describe alternating current tests. Many installations own adequate alternating current equipment. In many applications the use of alternating current is almost universal. For example, alternating current does a magnificent job in the field of materials testing, where breakdown tests are made on samples of insulating materials under identical test conditions, and where the samples are small enough that the capacitance currents may be neglected. For production testing of small consumer items, alternating current permits the use of a small high reactance (collapsing field) transformer type of test set which is unexcelled for operator safety and convenience. Alternating current is almost universally used for corona testing, where each alternation of voltage causes a repetition of the corona burst, where test set sophistication has reached high levels, and where quadrature current is relatively insignificant. Alternating current stresses a composite insulation structure in proportion to the dielectric constants of the materials, rather than in proportion to the leakage resistance, as is the case in direct current testing. When this is of significance or where the mechanical vibration or stresses produced by alternating current are desired, an alternating current test is needed. Most important, an alternating current test is necessary where the customer's specifications require it.

The alternating current high potential test is primarily a go/no-go test. The voltage is raised to a specified level, and if the equipment breaks down or shows signs of excessive leakage current, the item under test has failed. If the circuit breaker does not operate or the leakage indicator does not light, the item has passed. How close the equipment came to failure or by what margin it passed is not known. The test only indicates good or bad.

Advantages of DC

A direct current high potential test can do more than give a good or bad indication. It can indicate pretty good, or almost too bad. It frequently can indicate all right for now, but expect a failure soon. How much it indicates depends on the way the test is made, the equipment used, and the experience of the test operator. Direct current testing is preferred when the capacitance of the equipment to be tested is so high that an unreasonably large alternating current unit would be required. Direct current is used to obtain information regarding the comparative condition of equipment, as measured in periodic tests, or to make comparisons between similar types of equipment. While an alternating current set depends on the operation of a circuit breaker or leakage light for go/no-go failure indication, with a direct current unit the leakage current is measured as the test progresses and is the significant factor. Since acceptable values of leakage current may vary widely from equipment to equipment or from component to component, the absolute value is not as important as the relative value—the value compared to that obtained in other tests on similar equipment, or obtained in similar tests of the same equipment at other times.

AC/DC CONVERSION FACTOR

When a direct current high potential test is planned in place of an alternating current test, the question arises regarding the proper value of test voltage. Unfortunately, there has been no general agreement among all segments of the industry. Conversion factors (multiplying factor to be applied to the alternating test voltage to obtain an equivalent direct voltage) from as low as one to as high as nine have appeared in various specifications or have been used by various manufacturers or utilities. Segments of the aero-space industry have been using factors of 1.8 to 2, while many manufacturers of consumer items use a factor of 1.7. Many in the cable industry use conversion factors of 2, 3 or higher. The value of direct voltage to use when an alternating voltage has been specified must be determined by arbitration between the cognizant parties, arbitrarily, or by experimentation. The figure 1.7 probably appears more frequently than any other, but has by no means been accepted as the standard.

CORONA AND STRAY CURRENTS

When testing rotating machinery or cables with direct current, leakage currents of the order of magnitude of only a few microamperes are common. At these low levels, it is important that precautions be taken to minimize the effect of external corona or surface leakage which could obscure the measurement. A direct current test set capable of measuring these low values is usually equipped with bypass or guard circuit which, as the name implies, permits bypassing the unwanted stray currents around the metering circuit so that the test set microammeter indicates only the true leakage current. If, for example, it were necessary to measure the leakage current between a single phase and shield in a three phase shielded cable, the phase under consideration would be connected to the high voltage terminal, the shield to the

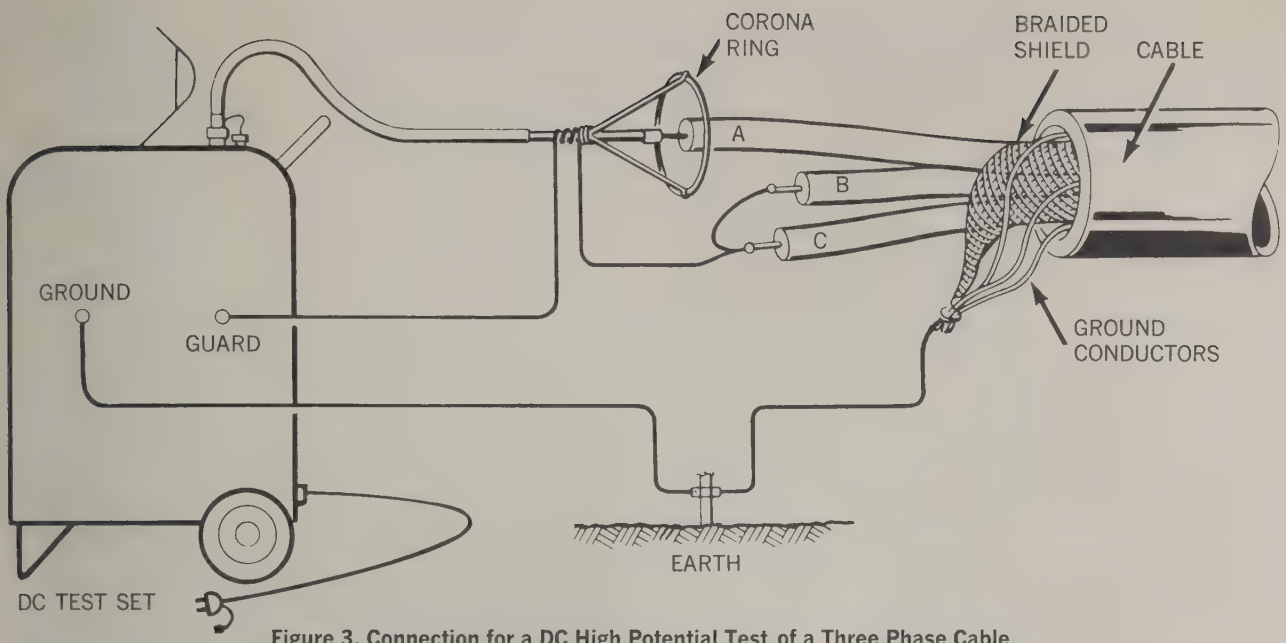

Figure 3. Connection for a DC High Potential Test of a Three Phase Cable Corona Ring and Connections to the Guard Circuit are Shown

ground return, and the other two phases to the bypass or guard circuit of the test set. The leakage current between the test phase and ground would pass through the metering circuit and be measured. The leakage current between phases, being connected to the guard circuit, would be bypassed around the meter and would not show up in the reading. In order to provide a return path to the guard circuit for external corona currents at the connections, a corona ring could be made by forming a piece of heavy bare wire into the shape of a loop 6 to 12 inches in diameter. It should be positioned around the cable end and connected to the guard terminal. Corona currents emanating at the connection would be captured by the guard ring and bypassed. A typical set up is shown in Figure 3.

DIRECT CURRENT HIGH POTENTIAL TEST TECHNIQUES

Direct current high potential tests are usually performed to determine the condition of the insulation in the neighborhood of and somewhat above the operating voltage. Probably the most popular test of this type is the "leakage current vs. voltage" test.

It is normally performed by applying the test voltage between each phase (in turn) and ground, or between one phase and all others tied to ground, depending on whether the total leakage current or the phase to ground leakage current is of interest. When testing a single phase cable or machine, the test potential, of course, is applied between the live circuit and the frame, shield, or ground. When particularly low leakage currents are expected, circuits not under test should be returned to the guard terminal of the test set. All connected loads, accessory equipment, potential transformers, etc. Must be disconnected from the cable or rotating machine prior to making the test to avoid additional shunt paths and to avoid the possibility of damaging lower voltage rated items.

Once the connections are made (see Figure 3), the voltage is slowly raised in discrete steps, allowing sufficient time at each step for the leakage current to stabilize. At each step the current will first reach a relatively high value (due to the capacitance and absorption currents) and then will decrease with time until the steady state leakage value is reached (as shown in Figure 2). The steady state value of leakage current is noted at each step of voltage, and as the test progresses, a curve of "leakage current vs. test voltage" is plotted. As long as this curve is relatively flat (equal increments of voltage giving equal increments of current as in Figure 4, points a to b), the item under test is considered to be in good condition. If the voltage is raised high enough, at some point, the current will start rising at a more rapid rate (Figure 4, point c). This will show up as a "knee" on the curve. It is very important that the voltage increments be made small enough in this area so that the start of the knee can be noted. If the test is carried on beyond this point, the current will increase at a much more rapid rate and breakdown will soon occur (Figure 4, point d). Unless breakdown is

actually desired, it is the usual practice to halt the test as soon as the beginning of the knee is observed, even if it should take place before the specified final test voltage is reached. Once the test operator has had sufficient experience, he can often extrapolate the curve and estimate the point at which breakdown might be expected.

In some cases the time for stabilization of the leakage current may run as high as several minutes or even several hours or more. To minimize the time required to perform a test under these conditions, it is common practice to time the decay of current and take a reading at each voltage step after the same fixed interval. As an example, the voltage would be brought up to the first step, allowed to remain at that point until it has substantially reached the steady state value, and then the current reading recorded. The voltage is then raised to the second step and the same time interval allowed before taking the second reading. This is continued throughout the test. While this method will not give the true leakage current at any point, it will give the properly shaped curve and will permit proper evaluation.

The important thing to watch for is the rate of change of leakage current with voltage. However, the actual value of current will yield much information. A comparison of the leakage current from phase to phase or a comparison with values measured in other similar equipment or in tests made on the same equipment on prior occasions will give an indication of the condition of the insulation. In general, the higher the relative value of leakage current the poorer the condition of the insulation. Although it is difficult to make a good evaluation from a single test, if the general shape of the curve is as shown in Figure 4, and if the knee occurs above the maximum required test voltage, the equipment under test may be considered satisfactory.

When the final test voltage is reached, a leakage current vs. time curve (similar to curve B in Figure 2) may be plotted by recording the current at fixed intervals as it decays from the initial high charging value to the steady state leakage value. In tests on good equipment, the curve should indicate a continuous decrease with time until the stabilized value is reached. Any increase in current during this test would be indicative of bad equipment, and the test, of course, should be stopped immediately. At the completion of the test, the high voltage should be shut off and the kilovoltmeter on the test set watched as it indicates the decay of voltage as the load and internal filter capacitors slowly discharge through the internal discharge circuits. The discharge may be speeded up by physically grounding the output using rubber gloves and a hot stick. After the voltage reaches zero an external ground should be connected and kept in place for a period several times longer than the time of application of voltage, to prevent the build-up of voltage which could otherwise take place due to the absorption current effects. It is important to wear rubber gloves when grounding the equipment because the absorption voltage build-up could reach dangerous values.

Preparation for the Test

A certain amount of preliminary work must be done before starting the test. In addition to the high potential test set and connecting cable, a clipboard, or other writing surface, pencils, scratch paper, and sheets of 8½ by 11 inch graph paper should be available at the test site. The maximum test voltage must be decided upon, taking into account the type of test, the rating, and the age of the equipment. As a rough rule of thumb, a test made soon after the equipment has been put into service might be conducted at 60% of the factory test voltage, while an acceptance test (a test made immediately after installation but prior to putting the equipment into service) might call for maximum values of about 80% of the factory test voltage. For maintenance testing or for tests on older equipment, the maximum test voltage might range from 1.7 times the operating voltage of the equipment to 50 to 60% of the factory test voltage. The factory test voltage (the voltage at which the manufacturer tests the equipment to determine compliance with design or production specifications) may be obtained from the original equipment manufacturer or from the various equipment or wire and cable manuals or specifications.

Once the final test voltage has been decided upon, suitable increments should be chosen so that the voltage may be raised to the final value in about 10 steps (more or less to suit the individual conditions). The

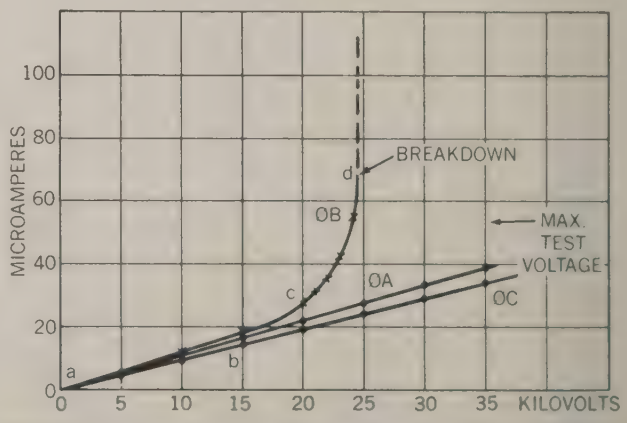

Figure 4. Leakage Current vs Voltage Curves for a Typical DC High Potential Maintenance Test on a 13.8 KV Generator Test Shows Failure of Phase B at 24 KV

graph paper may then be prepared so that the test results can be plotted as the readings are taken. In this manner the condition of the cable remains under constant surveillance, and the operator has necessary control to stop the test at the start of the knee of the curve if it should occur before reaching final voltage. It is usually convenient to prepare the graph paper by marking the current scale on the 8½ inch vertical side and the voltage scale along the horizontal 11 inch side. The current scale should include values well above the expected maximum leakage currents. If the magnitude of leakage current is not known, it may be advisable to make a low voltage preliminary run or to hold off plotting the first few points until the general order of values is seen. A sample set of curves (including indication of a faulted phase) is shown in Figure 4.

GO/NO-GO HIGH POTENTIAL TEST

The test described above will give a good indication of the condition and with proper interpretation may even allow a prediction of the expected life of the insulation. A careful performance, however, requires a considerable amount of time, experience, and skill both in conducting and in evaluating the operation. If the test operator is only interested in knowing whether or not the equipment can satisfactorily withstand a specified voltage for a specified length of time, a much shorter and simpler test may be sufficient.

The equipment is set up as before. The test voltage is then steadily raised to its final value at a rate which will keep the charging current just below the full scale reading of the test set microammeter. The voltage is maintained at the final value for the length of time required or, in the absence of any specified time, until after the current has stabilized for a minute or more. If the leakage current does not become excessive (remains below the maximum specified value or decays to a lower stabilized value, in the absence of a specified figure), the equipment has passed the test. Failure is indicated by a gradual or abrupt increase in current sufficient to trip the circuit breaker. This sudden increase in leakage current should not be confused with a high charging current. The high charging current may be minimized by slowing down the rate of rise of voltage—if the current seems to be rising too high, hold the voltage steady at that point and wait. If the current immediately starts decreasing, the indication is that of charging current, and the test may be continued. On the other hand, if the current does not decrease, or continues to increase, it is a definite sing of excess leakage or failure.

At the end of the test the voltage should be reduced to zero and the cable discharged as before.

INTERPRETATION OF RESULTS

When a high potential test is made to determine the maximum voltage that a material can withstand, there is a definite indication of the final point. When the material fails, the disruptive avalanche of current associated with breakdown operates the circuit breaker, causes arcing or flashover, and may give other audible or visible signs of breakdown. If the high potential test is made to determine the condition of the insulation up to a predetermined voltage level, the matter of interpretation becomes more difficult. It is impossible to establish a universal go/no-go figure for leakage current since a few microamperes may be excessive in some cases or for some equipment, while several milliamperes may be acceptable in others.

Alternating Current Test

In an alternating current high potential test the usual indication of failure is the operation of a fast acting magnetic circuit breaker or the glowing of the leakage indicator. For normal run of the mill, small, consumer type items, a leakage light setting of 0.5 milliamperes is common, while the maximum circuit breaker sensitivity is usually 10 milliamperes. If the item under test is sufficiently capacitive so that the quadrature current is significant, a higher value of leakage indication or a less sensitive circuit breaker setting is necessary. It is common practice to test a quantity of known good items and a few known bad items so that the leakage light or circuit breaker may be properly adjusted to pass the good and fail the bad. The problem is not as difficult as it sounds since the leakage or breakdown current of bad equipment is usually several orders of magnitude larger than the current in similar but good equipment.

Direct Current Test

For a direct current high potential test, the order of magnitude of leakage current compared with that of other known good equipment, or the shape of the leakage current vs. voltage curve are the commonly used criteria. As long as the knee of the curve (which indicates impending breakdown, as in Figure 4, point c) does not occur below the maximum required test voltage, and as long as the shape of the curve is not too steep compared with that of similar equipment, or with the same equipment tested on prior occasions, the results may be considered satisfactory. Unfortunately, in some cases, the knee of the curve almost becomes a right angle bend, and breakdown occurs simultaneously with the start of the knee. When this happens it is, of course, impossible to stop the test prior to breakdown.

INSULATION RESISTANCE MEASUREMENTS

The direct current high potential test set is an ideal instrument for making insulation resistance measurements at higher voltages. The insulation resistance may be calculated by dividing the voltage by the leakage current. If the insulation resistance is calculated at each voltage step as the leakage current vs. voltage test is made, curves of insulation resistance vs. voltage may be plotted. A curve of this type can yield much information to an experienced operator. Keeping records of the insulation resistance at a specific voltage, so that the readings may be compared from test to test, or from year to year, will give a good basis of comparison for proper insulation evaluation.

Insulation resistance may also be measured with a standard direct reading 500 volt (though units are available with operating potentials of 50 to 2500 volts) megohmmeter. The use of the megohmmeter is no substitute for a high potential test, since the insulation resistance has little or no direct relationship to the breakdown strength of the material. As an example, an actual void in the insulation may show an exceedingly high value of insulation resistance, although it might permit breakdown at a relatively low voltage. An insulation resistance test may be made before performing a high potential test merely to determine if equipment is good enough to warrant receiving the high potential test.

CONCLUSIONS

1. Alternating current high potential test sets find the widest application for go/no-go testing of small (low capacitance) equipment, for production testing of consumer items, materials tests, and for corona tests.
2. Direct current high potential test sets are generally employed where quantitative rather than qualitative results are necessary, in evaluating the relative condition of insulation, or when large equipment or cable runs (having high capacitance) must be tested.
3. A direct current high potential test usually takes longer to perform than an alternating current test because of the charging and discharging time required. The direct current test is also potentially more dangerous due to the possibility of voltage build-up (after the power is shut off) caused by absorption effects.
4. A direct current high potential test set may be much smaller in size and cost than the equivalent alternating current unit required for testing large or highly capacitive items.
5. Most existing specifications call for alternating current high potential tests. In many cases this is because of the lack of general familiarity with the newer, more sophisticated direct current test techniques, and availability of equipment, rather than because the alternating current test per se is better.
6. While there is no general agreement on AC/DC conversion factors, consumer equipment manufacturers tend to use the figure of 1.7 for production testing, aero-space industry manufacturers lean towards the figure of 2, while wire and cable manufacturers use a figure of 2 or 3 or even higher. Various public utilities use figures of 2 to 5 or higher in testing the larger rotating machinery.

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MODEL 5212-M1 - REPLACEMENT PARTS LIST

SYMBOL	PART NO.	DESCRIPTION
AMPV	15807	Amplivolt Assembly, 10 KV DC @ 2 MA
C-1	P10425	Capacitor, .5 mfd @ 600 V.
C-2	P14306	Capacitor, .01 mfd, 1,600 volts
CA-1	P11649	Cable Assembly, Input
CA-2	17337	Cable Assembly, H.V., 15 ft.
F-1	P107	Fuse, 3AG, 2 ampere (FUSE)
I-1	P14160	Indicator, clear (POWER)
I-2	P14159	Indicator, red (HIGH VOLTAGE)
M-1	P10959 w/16556	Meter, 50 MA DC, Kilovoltmeter, w/scale
M-2	P10959 w/16558	Meter, 50 UA DC, Microammeter, w/scale
NE-1, 2	P8591	Neon Lamp, NE-2
R-1, 2	P7031	Resistor, fixed; 100K ± 10%, 1/2 watt
R-3	P10735	Resistor, fixed; 1 Meg ± 1%, 1/2 watt
R-4	P10725	Resistor, fixed; 100K ± 1%, 1/2 watt
R-5	P11825	Resistor, fixed; 10K ± 1%, 1/2 watt
R-6	P14453	Resistor, fixed; 1K ± 1%, 1/2 watt
R-7	P15080	Resistor, variable; 1 Meg
R-8	P14898	Resistor, variable; 10K
R-9	P15294	Resistor, fixed; 500 ohms ± 1%, 1/2 watt
RY-1	P16568	Relay, DPDT
S-1	P5005	Switch, toggle; DPST (POWER)(OVERLOAD CURRENT)
S-2, 5	P9690	Switch, toggle; SPST (H.V.) (MICROAMMETER)
S-3	P16583	Switch, rotary; 3 pole, 4 position, shorting (MICROAMPERES)
S-4	P15481	Switch, rotary; 1 pole, 2 position (KILOVOLTS)
S-6	P16679	Switch, toggle; SPDT (GROUNDED)
SA-1	16235	Shunt Assembly
T-1	P11654	Transformer, variable
T-2	P11147	Transformer, H.V., 6 KV AC
TER-1	P11817	Terminal, black (BYPASS)
TER-2	P11818	Terminal, red (METERED)
TER-3	P17478	Terminal, nickel (GROUND)
VTUA	17645	Amplifier Assembly

COMPONENTS NOT SHOWN ON SCHEMATIC WIRING DIAGRAM

	17490	Cable Assembly, black (GROUND), 15 ft.
	15875	Cable Assembly, black (RETURN), 15 ft.
	15876	Cable Assembly, red (RETURN), 15 ft.
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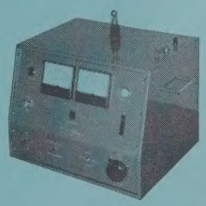

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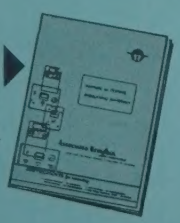

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